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# TECHNICAL NOTE

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INVESTIGATION OF A 10-CENTIMETER-DIAMETER ELECTRON-  
BOMBARDMENT ION ROCKET

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## SUMMARY

Previous investigations have proven the feasibility of the electron-bombardment ion source concept. This report deals with an improved 10-centimeter-diameter electron-bombardment ion rocket capable of operation in performance regimes above 10 millipounds of thrust. The source has been operated above 10 millipounds of thrust continuously for 10 hours at a specific impulse of 8500 seconds. The engine was also operated for 150 hours at 4 millipounds of thrust. The source has produced 0.5-ampere beam currents at as low an impulse as 5900 seconds, yielding a calculated thrust of 13 millipounds. Accelerator impingement currents have been on the order of 1 percent of the beam current. Mercury was used as a propellant during this investigation.

## INTRODUCTION

Previous investigations have proven the feasibility of the electron-bombardment ion source concept (ref. 1). In determining the performance of a new propulsion device it is a natural tendency to expand the performance envelope as rapidly as possible. The results of the initial investigation using a 10-centimeter source led to the design of a more advanced ion source (ref. 2). The ion rocket which is the subject of this report was fabricated to determine the performance that might be expected from a 10-centimeter-diameter electron-bombardment ion source ion rocket. The second beam source was improved mechanically and simplified electrically, and additional component versatility was provided.

This report deals with the major geometric and electrical parameters affecting the performance of the ion rocket. The ion-chamber geometry was varied by changing such parameters as the ion-chamber length, anode length, and filament position. As part of the ion-chamber investigation, two magnetic-field configurations were also used. The accelerator system was investigated using two different geometries. All electrical parameters were varied over the operational ranges of the ion rocket and

power supplies. The propellant flow rate was also varied. Mercury was used as the propellant throughout the investigation.

# SYMBOLS

$J$	current, amp
$\dot{m}$	mass flow, g/sec
$P$	power, w
$P_A$	accelerator power, $(V_I +  V_A )J_A$
$P_B$	beam power, $V_I J_B$
$P_F$	filament power, $\Delta V_F J_F$
$P_I$	ion-chamber power, $\Delta V_I (J_I - J_B)$
$P_M$	magnet power, $\Delta V_M J_M$
$P_T$	total power, $P_B + P_I + P_M + P_F + P_A$
$V$	potential, v
$\Delta V$	potential difference, v
$\eta_p$	overall power efficiency, $P_B/P_T$
$\eta_u$	propellant utilization efficiency, $\dot{m}_B/\dot{m}_T$

## Subscripts:

A	accelerator
B	beam
c	calculated
E	emission
F	filament
I	ion chamber
M	magnetic field

m measured  
 SD screen distributor  
 T total  
 t target

## APPARATUS AND PROCEDURE

### Engine

The engine is shown in figure 1. A cutaway sketch is included in figure 2. The propellant flows through a calibrated orifice between the boiler and the flow distributor. After leaving the distributor, the flow enters the ion chamber. A field winding surrounding the ion chamber provides a magnetic field roughly parallel to the axis of the ion chamber. Electrons from a hot filament on the axis of the ion chamber bombard the neutrals in the ion chamber, ionizing some of them. The ions of interest pass through the screen which, assuming correct operation, shields the accelerator. The entire engine, with the exception of hot filaments, insulators, the field windings, and one set of accelerator grids, was fabricated of nonmagnetic stainless steel.

Boiler. - Steam at atmospheric pressure was used to heat the double-walled boiler, providing very close thermal control with a minimum of mechanical complexity. The size of the removable calibrated orifice was varied to change propellant flow rates.

Distributor. - The purpose of the distributor is to distribute the flow across the cross section and to shield the high-density flow near the orifice from possible electrical discharges. The distributor used should give an approximately uniform flow distribution across the ion-chamber cross section.

Ionization chamber. - The region between the distributor and the screen is referred to as the ionization chamber. The ionization chamber contains the cylindrical anode and the axial filament. Several chamber lengths and anode lengths are discussed. The filament is a 0.25-millimeter-diameter tantalum wire 2 to 3 centimeters long supported by rods at the axis of the chamber. The filament support rods and anode supports ran through boron nitride insulators, which fitted into tubes running radially outward from the chamber.

Accelerator system. - Two different sets of grids were used as accelerators during this investigation. The first screen and accelerator were constructed of tungsten rods 0.16 centimeter in diameter on

0.51-centimeter lateral centers. The rods were free at the ends so that thermal expansion could take place without causing bowing. When assembled, the axial centerline spacing of the two grids was 0.51 centimeter.

The second set of grids, using 0.48-centimeter axial spacing, was composed of two 0.18-centimeter-thick stainless-steel plates. The plates were drilled with 0.48-centimeter-diameter holes in a hexagonal pattern with 0.64-centimeter center-to-center spacing. The plates were drilled while clamped together to ensure hole alignment.

Field winding. - Enameled copper wire supported on boron nitride blocks was used for the magnetic-field winding. A modified Helmholtz configuration with 64 turns of number 16 wire in each coil was used to give an approximately uniform axial field throughout the ionization chamber. A nonuniform magnetic field was provided by one coil of 120 turns of number 16 wire positioned axially to give the desired degree of field variation throughout the ion chamber. The mean diameter of all the hexagonal shaped coils was 25 centimeters.

Insulators. - Ball insulators were used for all high voltages. All the balls were of fused aluminum oxide about 5 millimeters in diameter (3/16-in. stock size of synthetic sapphire). Some insulators, such as the filament support insulators and the field winding supports, were fabricated of boron nitride. The boron nitride insulators were not subjected to more than 100-volt potential differences.

Assembly of components. - The ionization chamber was bolted directly to the screen grid. The flanges of the screen grid, accelerator grid, and coil mount were fabricated with holes smaller than the insulating balls, so that the balls both positioned and separated the components. Three bolts ran through the assembly to provide the axial compression to keep the balls in place. The flexibility of thin metal sections permitted thermal expansion.

Neutralizer. - A neutralizing filament (20-cm-long, 0.25-mm-diam. tantalum wire) was stretched across the ion beam about 25 centimeters downstream of the engine. A direct current was used to heat the wire (about 100 w), and the negative end was grounded to the vacuum facility. This device was installed primarily to stabilize operation of the ion accelerator. At high beam power levels the wire was moved to the edge of the beam to reduce the erosion due to the ion impingement and prolong the neutralizer filament life.

Electrical system. - A schematic diagram of the electrical system is shown in Figure 3.



## Facility

The installation of the engine in one of the 5-foot-diameter, 16-foot-long vacuum tanks at the NASA Lewis Research Center is shown in figure 4. The tank has three 32-inch oil diffusion pumps feeding into a common ejector pump, followed by a mechanical pump. With cryogenic pumping used in conjunction with the preceding pumps, engine operation was possible in the  $10^{-6}$ -millimeter-of-mercury pressure range. A more complete description of this facility is included in reference 3.

## RESULTS AND DISCUSSION

Experimental results will be discussed in the following order:

(1) ion-chamber performance, (2) general characteristics of the accelerator system, (3) ion-chamber - accelerator system interactions, (4) overall engine performance and reliability, and (5) ion-beam thrust and associated target measurements.

### Ion-Chamber Performance

A measure of ion-chamber efficiency is the energy dissipated in the ion-chamber discharge per beam ion. In the early configurations where the flow of ionizing electrons was very much greater than the beam current, the power used in the ionization process was regarded as the current collected by the anode times the ion-chamber potential difference. As the beam current, and hence the secondary electron current, became a larger percentage of the current collected by the anode, the ion-chamber loss term was corrected to account for the secondary electrons. The losses are properly written as the ion-chamber potential difference times the difference between the current collected by the anode and the beam current. The power dissipated in the ion-chamber discharge, in electron volts per beam ion, is then arrived at by dividing this dissipated power term by the beam current.

Typical ion-chamber performance for this particular type of electron-bombardment source is shown in the curve of figure 5. The energy dissipated in the ion-chamber discharge is plotted against the ion-chamber potential difference for a constant beam current. As ion-chamber potential difference is lowered, the efficiency of the ion production process increases until a minimum ion-chamber energy is reached at a potential difference of 40 to 50 volts. Below this voltage level large emission currents are required to maintain a given beam current because of the decreasing probability of ionization, that is, cross section (ref. 1). The discharge losses rise and rapidly approach the emission limit of the filament. When a minimum energy is not attained, it is usually due to this emission limit.

Magnetic-field strength. - The effect of magnetic-field strength on ion-chamber performance is shown in figure 6. The energy dissipated in the ion-chamber discharge in electron volts per beam ion is plotted against the magnetic-field strength at the center of the filament. The nonuniform-magnetic-field configuration was used. The ion-chamber potential difference was 50 volts. A 0.125-ampere beam current was maintained at a specific impulse of 7000 seconds. The propellant utilization efficiency was 80 percent. The 1-centimeter anode was positioned at the plane of the center of the filament. The chamber length was 5 centimeters.

The losses drop very rapidly with increasing magnetic-field strength up to about 30 to 35 gauss. After reaching this value the losses tend to level out but still decrease slightly with increasing field strength. The optimum condition is naturally the point at which the sum of chamber losses and magnetic-field losses is minimized.

Magnetic-field shape. - Two magnetic-field shapes were investigated during this program. An approximately uniform field was provided by a Helmholtz coil configuration, modified to give slightly less uniformity but over a greater axial length. The nonuniform field was arranged to give a field at the screen which was 65 percent of the field strength at the distributor when the screen and distributor were approximately 10 centimeters apart. The field strength quoted, in this case, is the field strength 5 centimeters upstream of the screen, the point at which the center of the filament was positioned for the field shape tests. No attempt was made during this investigation to ascertain the optimum magnetic-field configuration.

The effect of the magnetic-field shape on ionization-chamber performance is shown in figure 7. The energy dissipated in the ion-chamber discharge per beam ion is plotted against the ion-chamber potential difference. The upper curve was taken with the uniform magnetic field at a strength of 30 gauss. The lower curve was obtained with a decreasing field in the downstream direction with the 30-gauss strength located at the center of the filament. The beam current was 0.125 ampere and the specific impulse 7000 seconds. The propellant utilization efficiency was again 80 percent. The ion-chamber performance improved when the field strength was decreased in the downstream direction. This trend held for all anode configurations tested during the balance of the investigation.

An explanation of the improved efficiency with the nonuniform magnetic field might be the concentration of high-velocity ionizing electrons at the downstream end of the chamber, so that a greater fraction of the ions produced find their way into the ion beam. Another possible explanation is that the nonuniform magnetic field produces an axial

variation of low-velocity electron density, which, in turn, produces an electric field that tends to direct ions in the downstream direction.

Ion-chamber length. - A considerable portion of the losses incurred in the ion chamber may be due to recombination at the chamber walls, anode, and distributor. Possible performance gains might be expected by reducing the amount of metal surface available to the plasma boundary. To investigate this supposed effect and also to determine possible minimum dimensions of the ion source, the ionization chamber was operated at three lengths: 5, 10, and 17 centimeters. A 1-centimeter-wide anode was used with all three lengths, and the filament was centered at the plane of the anode.

Figure 8 shows the results of these tests. Again, the chamber losses in electron volts per ion are plotted against ion-chamber potential difference for each of the three chamber lengths. The beam current was 0.125 ampere and the impulse 7000 seconds. The propellant utilization efficiency was 80 percent. Figure 8(a) indicates that with the uniform magnetic field the performance improved (lower energy loss per beam ion in the discharge) as the ion chamber was shortened.

The data of figure 8(b), for which the nonuniform magnetic field was used, show the same general improvement as the chamber length was shortened from 17 to 10 centimeters. However, the chamber performance remained substantially the same as the chamber was shortened further. For these tests the 30-gauss field strength was maintained at the center of the filament.

The general trend of results, then, tends to support the theory that the chamber losses increase with chamber area, particularly for the two longest chambers. The lack of improvement in performance for the shortest chamber, especially with the nonuniform magnetic field, indicates that the wall and end areas are not the only significant parameters involved.

Anode length. - Figure 9 shows the effect of reducing the anode length from 15 to 1 centimeter. The discharge loss per beam ion is plotted against the ion-chamber potential difference for a 0.125-ampere beam. The impulse and propellant utilization efficiency are again, respectively, 7000 seconds and 80 percent. In a preliminary report on this electron-bombardment source (ref. 2), it was shown that there was little ion-chamber performance variation for a wide difference in anode length at low beam currents. The results of reference 2 are supported by those of the present investigation at a higher beam current. The two curves of figure 9 show that the performance of the 15- and 1-centimeter anodes is similar with the uniform magnetic field. The two lower curves show that with the nonuniform magnetic field the performance of the chamber with each of the anodes is again very similar. Comparison of

the upper and lower pairs of curves indicates that the beneficial effect of the nonuniform field is slightly greater with the 1-centimeter anode. Similar performance has been obtained with the divergent magnetic field with other anode lengths between 1 and 8 centimeters.

As was shown in the previous section, reducing the wall area reduced ion-chamber losses. Thus, the number of ions recombining on that wall area is probably not negligible. The insensitivity of the ion-chamber losses to anode changes for the same ion-chamber length further indicates that it is unimportant whether this cylindrical wall area is at anode or distributor potential.

In general, the shorter anodes (less than 3 cm) tended to be hard starting in that a higher chamber potential difference has to be used to start the discharge. The discharge was also relatively unstable at low chamber potential differences.

Filament position. - From the data taken during the chamber length tests it was felt that the position of the filament with respect to the divergent field and chamber hardware might have some bearing on the performance of the ion chamber. Figure 10 shows the results of an attempt to determine the effect of axial filament location on the efficiency of the ionization process. The tests were conducted with a 7.5-centimeter-long anode and a 10-centimeter-long chamber. The 3-centimeter-long filament was positioned at the maximum possible upstream or downstream locations. The characteristics were investigated at beam currents of 0.125 and 0.060 ampere. Propellant utilization efficiency was constant at 80 percent and specific impulse at 4500 seconds.

Figure 10(a) shows that the maximum efficiency for both filament positions occurs at an ion-chamber potential difference of 70 volts. The downstream filament gives the best performance at the 0.060-ampere beam current. As mentioned in the general discussion of ion-chamber characteristics, the sharp rise of the dissipated energy below 60 volts for the 0.060-ampere beam is associated with very large emission currents.

Maintaining the same magnetic-field strength in the center of the chamber (5 cm from the screen) and approximately doubling the beam current gave the results shown in figure 10(b). The shape of the two curves is the same, but in this case the upstream filament has superior performance.

It appears, then, that at a beam current of 0.060 ampere a downstream filament location gives better performance, while at a beam current of 0.125 ampere an upstream filament position is superior. It should be pointed out, however, that the difference is, at most, less than 20 percent.

Ion-beam current. - In addition to the effect of filament position, figure 10 also shows the effect of changing the ion-beam current from 0.060 to 0.125 ampere at a specific impulse of 4500 seconds. The effect of this current change was greatest at low ion-chamber potential differences. At 0.060-ampere operation was very inefficient below about 30 volts, while at 0.125 ampere efficient operation could be obtained at the emission limit of the filament at 40 volts. The minimum energy per ion changed less drastically, being about 670 electron volts at 0.060 ampere and 625 electron volts at 0.125 ampere.

Since the performance improved in increasing the ion-beam current from 0.060 to 0.125 ampere, it was of interest to see if a further increase would cause additional improvements. A comparison of ion-chamber performance at 0.125 and 0.25 ampere is shown in figure 11.

The energy dissipated in the ion-chamber discharge per beam ion is plotted against ion-chamber potential difference at a specific impulse of 7000 seconds. The 1-centimeter anode was positioned at the center of the 10-centimeter-long chamber. The propellant utilization efficiency was 80 percent of all beam currents. The 0.125-ampere curve reached a minimum of 380 electron volts per ion at a chamber potential difference of 40 volts. The minimum was not reached at 0.25 ampere because of filament emission limitations. The lowest loss at 0.25 ampere was 530 electron volts per ion. The losses at the higher density condition also increase more rapidly with increasing ion-chamber potential difference.

The decrease in performance (increase in losses) when going from 0.125- to 0.25-ampere beam current has been noted with several other source geometries and appears to be a general phenomenon associated with this size source.

#### Accelerator Performance

Figure 12 gives a qualitative picture of the beam power distribution for the plate and wire accelerator grid systems. The contours were drawn from data obtained with hot wire and conventional calorimeter traces and with some assistance from observations of impingement patterns at the calorimeter station and projections of patterns on hardware farther downstream. The contours are representative of the power distribution 1 meter from the accelerator system and are given as percents of the maximum value.

As seen in figure 12(a), the power distribution from the plate grids has fairly good radial symmetry. Fifty percent of the beam power is included in a  $20^\circ$  solid angle. The beam current was 0.125 ampere at a specific impulse of 5000 seconds.

The large spread in the power distribution from the wire grids, shown in figure 12(b), is normal to the axis of the grid wires. Fifty percent of the beam power is contained in an elliptical cone estimated to be about  $20^\circ$  by  $45^\circ$ . The beam current was 0.125 ampere at a specific impulse of 6300 seconds.

Figure 13 shows the current density profile across the beam approximately 12 centimeters downstream of the accelerator system. The plot was obtained by recording the impingement current on a 0.475-centimeter-diameter molybdenum disk as it traversed the beam on the horizontal centerline of the engine. The trace was taken using the plate grid accelerator system and operating at 0.125-ampere beam current and a specific impulse of 6000 seconds. The highest current value recorded, at the axis of the source, gave a current density of 37.2 amperes per square meter. The average current density arrived at by dividing the total beam current by the source area is approximately 15 amperes per square meter. The average current density based on the accelerator open area is then about 30 amperes per square meter with a 0.125-ampere beam.

Accelerator impingement currents of less than 1 percent of the beam current could be obtained with both the wire and the drilled plate accelerator systems (fig. 14). The blockage of the wire grids was 37 percent, while that of the plates was 43 percent. The wire grids held the higher voltages (5 to 8 kv) much better than the plate grids. This effect is felt to be due to the sputtering properties of the tungsten wires compared to the stainless-steel plates (8 to 12 percent nickel). Erosion patterns on each set of grids showed that the current density was greatest at the center of the source. The effect of varying accelerating potential is shown in figure 14. The beam current was 0.25 ampere. The propellant utilization efficiency was 80 percent. The non-uniform magnetic field was used, and the ion-chamber potential difference was maintained at approximately 50 volts.

The point where the impingement current rises rapidly with decreasing potential is at the approximate current carrying capacity of the grids. The plate grids, having a slightly shorter acceleration length and perhaps better physical alignment, have better current carrying characteristics at the lower voltages.

#### Accelerator System - Ion-Chamber Interactions

The relative effects of the various geometry changes investigated are not altered by the impulse level, but the absolute performance level is. Data are available in table I to duplicate, at a lower impulse, most of the figures presented thus far. Figure 15 shows the effect of specific impulse on ion-chamber performance for a 0.25-ampere beam at a propellant utilization efficiency of 80 percent. The ion-chamber

potential difference was 50 volts except for the points below 6000 seconds where it had to be raised to keep from exceeding the emission limit of the filament. The nonuniform magnetic field was used along with the drilled plate accelerator system.

The power dissipated in the ion-chamber discharge per beam ion drops rapidly from a value of nearly 1000 electron volts per ion at a specific impulse of 5000 seconds to a value of 550 electron volts per ion at about 8600 seconds. This effect is probably due to the increased penetration of the accelerator electric field back through the holes in the screen at the large potential differences associated with high impulses.

#### Overall Engine Performance

The data of table II are indicative of the performance obtainable with this 10-centimeter-diameter electron-bombardment ion rocket. The point with a 0.35-ampere beam at a 6300-second impulse yields a calculated thrust of 10 millipounds. This operating point was held for 10 hours. All the data points except the last five were taken with the stainless-steel plate grids. The last four were taken with the tungsten wire grids. The point at 0.51-ampere beam current at an impulse of 5900 seconds (fifth row from bottom, table II) was taken with molybdenum plate accelerators with 0.24-centimeter-diameter apertures.

The highest efficiency attained during this investigation was 87 percent at a 7750-second impulse. At this impulse and efficiency 206 kilowatts would be required to generate 1 pound of thrust from an array of this type of source.

These data are not presented as representing ultimate or optimum values but only the present state of the art for experimental hardware. Further improvements should certainly be possible in the future. For example, replacing the field coil with a permanent magnet would increase the maximum measured efficiency of 87 to about 89 percent. The efficiency at 5000 seconds would be similarly increased from about 64 to 69 percent.

#### Endurance Test

To determine the extent of damage to the accelerator during long periods of time, the rocket was operated with a molybdenum accelerator system for 150 hours at a thrust level of 4 millipounds. The beam current was 0.20 ampere at a specific impulse of 5000 seconds. Figure 16(a) shows a general view of the center of the upstream face of the accelerator after the 150-hour run. Figure 16(b) shows a closeup of the

center hole of the accelerator before and after the 150-hour run. The five deep pits surrounding the hole are merely marks to locate the hole.

During the endurance run approximately 230 grams of propellant were accelerated through the grid system. The weight loss of the accelerator was 2.3 grams or about 1 percent of the accelerated propellant mass. No change in plate thickness could be measured with a micrometer. The total time on the accelerator system used for the endurance run was over 200 hours at the conclusion of the run. The useful lifetime of the accelerator system is estimated to be over 1000 hours.

#### Thrust Target

A 30-centimeter-diameter, 0.5-millimeter-thick stainless-steel disk was mounted on a differential transformer deflection pickup and used as a thrust target during part of the investigation. Thrust measurements were made at comparatively low beam power levels. The maximum target mass was limited by the flexure plates of the pickup to less than 50 grams, thus limiting the size of the disk. Thrust values up to 2 millipounds were observed. Even at these low thrust values the stainless target, located 1 meter from the engine, was heated to incandescence. Previous runs with an aluminum target had resulted in the destruction of the disk.

Because of the weight limitations imposed by the pickup flexure plates, no attempt was made to suppress secondary electrons or trap any sputtered material. The target was isolated electrically so that potential buildup might be measured. Figure 17(a) shows the effect of the neutralizer wire in the beam on the target potential for a range of specific impulse. The maximum potential buildup on the target was +12 volts when the neutralizer was on. When the neutralizer emission was shut off, the potential rose to as much as +1750 volts.

The ion-beam currents intercepted by the target were found by grounding the target through an ammeter. The currents thus obtained are shown in figure 17(b). Because of the deflection of ion trajectories for the floating target potentials measured, the ion-beam current striking the target should be somewhat less than the measured values when the target is isolated electrically and the neutralizer is not used.

The thrust data obtained with the neutralizer on are shown in table III. For the plate accelerator system, the target currents shown in figure 17(b) were used to estimate the percentage of the beam which impinged on the thrust target.

The measured thrust varied from 65 to 96 percent of the estimated value based on beam interception. For the wire grids, the percent of



beam striking the target was estimated from the power distribution profiles of figure 12 to be on the order of 40 to 45 percent. Using the 45-percent rate, the measured thrusts were 71 to 88 percent of the estimated values. If the 40-percent figure is correct, 80 to 98 percent of the estimated thrust was registered by the target.

Since the floating target potential with the neutralizer on was only a few volts, ion trajectories should have been the same whether or not the target was isolated. The momentum effect of sputtered particles should introduce an error, perhaps of the order of 10 percent. The largest errors, however, are probably associated with the estimated percentages of beam interception, which were based on current measurements, both the currents as determined from beam surveys and that from grounding the target. These current measurement errors, which are due to secondary electrons, can easily explain the observed discrepancies between measured and estimated target thrust.

### CONCLUSIONS

A nonuniform magnetic field, decreasing in strength in the downstream direction, improves ion-chamber performance. The optimum field strength is approximately 30 gauss at the screen for a 10-centimeter-diameter ion source.

Anode shape is not critical as far as ion-chamber losses are concerned, but shorter chambers (less than 10 cm) perform better than longer chambers. One beneficial effect of a long anode over a short anode for a given chamber length is ease of starting in that a lower potential difference is necessary to start the discharge.

The effect of filament position is significant but depends on ion-beam current.

The minimum ion-chamber discharge losses for the 10-centimeter-diameter ion source occurred at an ion-beam current of 0.125 ampere. The penalties associated with operation at higher or lower ion-beam currents were not large, however, at least for the range investigated from 0.060 to 0.25 ampere.

Accelerator impingement currents of the order of 1 percent of ion-beam current were obtained at impulses from 5000 to 8400 seconds at ion-beam currents up to 0.4 ampere. The life of currently available accelerator systems, estimated from the results of a 150-hour endurance run, should be at least 1000 hours.

Overall power efficiencies of up to 87 percent have been attained with the rocket reported herein.

The thrust measurements made with a thrust target were in substantial agreement with the calculated values from current and voltage measurements.

Lewis Research Center  
National Aeronautics and Space Administration  
Cleveland, Ohio, September 13, 1961

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E-1433

TABLE I. - ION-CHAMBER DATA

(a) Effect of magnetic-field strength. Beam current (common ground),  $J_B$ , 0.125 ampere; ion-chamber potential difference,  $\Delta V_I$ , 50 volts; ion-chamber potential,  $V_I$ , 4900 volts; accelerator potential,  $V_A$ , -1250 volts; propellant utilization efficiency,  $\eta_u$ , 80 percent; chamber length, 5 centimeters; anode length, 1 centimeter; plate accelerators; nonuniform magnetic field

Magnetic-field strength at filament, gauss	Magnetic-field current, $J_m$ , amp	Current collected by anode, $J_I$ , amp	Current collected by accelerator, $J_A$ , amp	Energy dissipated in discharge per beam ion, ev/ion
18.5	4.5	3.20	0.00105	1230
20.5	5.0	2.60	.00082	990
24.6	6.0	1.80	.00083	670
28.7	7.0	1.50	.00082	550
32.8	8.0	1.40	.00086	510
36.9	9.0	1.25	.00085	450
41.0	10.0	1.20	.00087	430
44.1	11.0	1.18	.00085	422
49.2	12.0	1.17	.00085	418
53.3	13.0	1.15	.00090	410
57.4	14.0	1.15	.00087	410
61.5	15.0	1.10	.00088	390
65.6	16.0	1.15	.00090	410
69.7	17.0	1.10	.00095	390
73.8	18.0	1.10	.00090	390
77.9	19.0	1.10	.00090	390
80.0	19.5	1.10	.00090	390

TABLE I. - Continued. ION-CHAMBER DATA

(b) Chamber length and magnetic field shape. Beam current (common ground),  $J_B$ , 0.125 ampere; plate accelerators; propellant utilization efficiency,  $\eta_u$ , 80 percent

Magnetic field shape	Ion-chamber potential, $V_i$ , v	Accelerator potential, $V_A$ , v	Magnetic field potential difference, $\Delta V_y$ , v	Magnetic field current, $J_M$ , amp	Ion-chamber potential difference, $\Delta V_i$ , v	Current collected by anode, $J_i$ , amp	Current collected by screen and distributor, $J_{SD}$ , amp	Current collected by accelerator, $J_A$ , amp	Energy dissipated in discharge per beam ion, eV/ion
Chamber length, 5 cm; anode length, 1 cm									
Uniform	2500	-1000	11	7.25	90	2.15	0.74	0.0013	1460
	↓	↓	↓	↓	85	2.13	.68	.0013	1362
					80	2.15	.65	.0012	1295
					75	2.27	.61	.0012	1287
					70	2.25	.54	.0012	1190
					65	2.29	.46	.0011	1120
					60	2.32	.38		1034
					55	2.42	.29		1010
					50	2.52	.17		958
					45	2.70	.10	.0010	989
	4900	-1250	11	7.25	90	1.72	.64	.0015	1147
	↓	↓	↓	↓	85	1.63	.57	.0014	1058
					80	1.65	.51	.0014	976
					75	1.63	.47	.0014	944
					70	1.61	.42	.0013	832
					65	1.70	.33		819
					60	1.73	.34		770
					55	1.80	.28		737
					50	1.80	.19		670
					45	1.95	.10	.0012	657
					40	2.20	0	.0011	664
Non-uniform	2500	-1000	7.5	7.0	90	1.40	----	.0008	918
	↓	↓	↓	↓	80	1.40			817
					70	1.33			708
					60	1.47			645
					55	1.45			593
					50	1.52			553
					45	1.50			531
					40	1.75			520
	4900	-1250	7.5	7.0	90	.95	.15	.00085	675
	↓	↓	↓	↓	85	1.00	.15	.00080	672
					80	1.00	.12	.00085	632
					75	1.00	.10	.00084	593
					70	1.05	----	.00075	556
					65	1.07	----	-----	516
					60	1.10		-----	478
					55	1.10		.00072	439
					50	1.15		.00070	410
					45	1.30		.00070	423
					40	1.40		.00071	408
					35	1.50		.00071	469
Chamber length, 10 cm; anode length, 1 cm									
Uniform	2500	-1000	11	7.25	90	2.57	0.81	0.0012	1532
	↓	↓	↓	↓	85	2.55	.72	.0011	1651
					80	2.43	.64		1508
					75	2.34	.60		1450
					70	2.50	.53		1330
					65	2.55	.48		1262
					60	2.62	.42		1193
					55	2.65	.34		1111
					50	2.78	.22		1055
	4900	-1250	11	7.25	90	1.55	.52	.0014	1240
	↓	↓	↓	↓	85	1.75	.63	.0014	1105
					80	1.72	.50	.0014	1021
					75	1.73	.49	.0013	1005
					70	1.90	.42	.0012	925
					65	1.85	.38	.0013	893
					60	1.90	.34	.0013	852
					55	1.94	.30	.0012	799
					50	2.10	.25	.0012	790
					45	2.30	.17	.0012	782
					40	2.53	----	-----	804
Non-uniform	2500	-1000	6.5	6.0	95	1.24	0.37	0.0002	758
	↓	↓	↓	↓	90	1.29	.37		739
					85	1.29	.36		693
					80	1.23	.35		647
					75	1.35	.34		637
					70	1.37	.33		597
					65	1.43	.32		574
					60	1.51	.30		554
					55	1.68	.28		552
					50	1.86	.22		541
					45	.99	.25		547
	4900	-1250	7.0	6.0	90	1.02	.24	.0002	500
	↓	↓	↓	↓	80	1.05	.23		444
					75	1.12	.22		439
					70	1.15	.20		410
					65	1.22	.19		384
					60	1.30	.16		378
					55	1.52	.07		430

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TABLE I. - Continued. ION-CHAMBER DATA

(b) Concluded. Chamber length and magnetic-field shape. Beam current (common ground),  $J_B$ , 0.125 ampere; plate accelerators; propellant utilization efficiency,  $\eta_u$ , 80 percent

Magnetic-field shape	Ion-chamber potential, $V_i$ , v	Accelerator potential, $V_A$ , v	Magnetic-field potential difference, $\Delta V_M$ , v	Magnetic-field current, $J_M$ , amp	Ion-chamber potential difference, $\Delta V_i$ , v	Current collected by anode, $J_i$ , amp	Current collected by screen and distributor, $J_{SD}$ , amp	Current collected by accelerator, $J_A$ , amp	Energy dissipated in discharge per beam ion, eV/ion
Chamber length, 17 cm; anode length, 1 cm									
Uniform	2500	-1000	11	7.25	95	2.70	0.35	0.0020	1568
	↓	↓	↓	↓	90	2.72	.35	.0020	1570
					85	2.75	.35	.0019	1745
					80	2.85	.35	.0018	1745
					75	2.90	.35		1533
					70	2.90	.35		1533
					65	3.10	.75		1542
					60	3.05	.65		1408
					55	3.15	.675		1342
					52	3.20	.67		1250
	4900	-1250	11	7.25	90	2.00	.75	.0013	1350
	↓	↓	↓	↓	85	1.94	.72		1252
					80	2.05	.74		1250
					75	2.05	.69		1174
					70	2.05	.67		9
					65	2.27	.65		1115
					60	2.35	.65		1063
					55	2.45	.65		1024
					50	2.55	.55		1021
					45.5	2.55	.52		955
Non-uniform	2500	-1000	7.0	6.0	80	1.95	0.335	0.0014	1158
	↓	↓	↓	↓	75	2.00	.32		1125
					70	2.00	.32		1150
					65	2.15	.30		1052
					60	2.15	.37		987
					55	2.22	.35		877
					50	2.30	.30	.0013	870
					45	2.50	.42	.0013	855
					40	2.35	.27	.0014	872
	4900	-1250	7.1	6.2	90	1.40	.42	.0017	915
	↓	↓	↓	↓	75	1.50	.45	.0016	825
					70	1.53	.45	.0015	797
					65	1.62	.40	.0015	775
					60	1.70	.44	.0015	756
					55	1.70	.40	.0016	654
					50	1.55	.40	.0015	691
					45	1.95	.35		657
					40	2.13	.25		641
					37	2.72	.22		765
Chamber length, 17 cm; anode length, 15 cm									
Uniform	4900	-1250	11	7.25	85	1.90	-----	0.0010	1139
	↓	↓	↓	↓	80	1.85			1105
					75	1.92			1075
					70	2.05			1079
					65	2.15			1052
					60	2.30	0.37		1042
					55	2.35	-----		980
					50	2.50	.70		850
					45	2.50	-----		829
Non-uniform	4900	-1250	7.0	6.0	85	1.47	0.24	0.0011	915
	↓	↓	↓	↓	80	1.50	.24		830
					75	1.54	.25		843
					70	1.55	.25		799
					65	1.68	.27		803
					60	1.75	.29		780
					55	1.90	.29		737
					50	1.90	.27		710
					45	1.95	.25		657
					40	2.30	.15	.0012	638
					35	2.40	.15	.0011	691

TABLE I. - Continued. ION-CHAMBER DATA

(c) Filament position. Ion-chamber potential,  $V_I$ , 2000 volts; accelerator potential,  $V_A$ , -1000 volts; chamber length, 10 centimeters; anode length, 7.5 centimeters; plate accelerators; nonuniform magnetic field; propellant utilization efficiency,  $\eta_u$ , 80 percent

Filament position	Magnetic-field potential difference, $\Delta V_y$ , v	Magnetic-field current, $J_y$ , amp	Ion-chamber potential difference, $\Delta V_I$ , v	Current collected by anode, $J_I$ , amp	Current collected by screen and distributor, $J_{SD}$ , amp	Current collected by accelerator, $J_A$ , amp	Filament heating potential difference, $\Delta V_f$ , v	Filament heating current, $J_f$ , amp	Energy dissipated in discharge per beam ion, ev/ion			
Beam current (common ground), $J_B$ , 0.060 amp												
Upstream	8.0 ↓	7.0 ↓	97	0.52	-0.018	0.0002 ↓	---	---	907			
			90	.52	-.011				840			
			85	.53	-.006				809			
			80	.57	.005				813			
			75	.55	.010				775			
			70	.70	.029				750			
			65	.75	.050				755			
			60	.52	.053				761			
			55	1.22	.155				1050			
			Down-stream	8.0 ↓	7.0 ↓				97	0.52	-0.035	0.0002 ↓
90	.50	-.013				810						
85	.51	-.007				773						
80	.53	-.025				707						
75	.53	-.025				662						
72	.52	-.006				673						
70	.57	-.005				712						
65	.53	.002				673						
60	.52	.056				760						
Beam current (common ground), $J_B$ , 0.125 amp												
Upstream	8.0 ↓	7.0 ↓	97	1.42	0.27	0.0011 ↓	5.4	6.1	1005			
			90	1.45	.29				.0012	5.4	6.1	956
			80	1.41	.30				.0013	5.5	6.1	823
			70	1.47	.29				↓	5.7	6.2	754
			60	1.55	.25				↓	5.7	6.3	684
			55	1.52	.26				↓	5.5	6.3	653
			50	1.70	.23				↓	6.0	6.3	630
			45	1.36	.19				↓	6.2	6.5	621
			40	2.15	.06				.0014	6.5	6.8	638
			97	1.36	.17				.0012	6.0	6.1	1440
	6.5 ↓	5.5 ↓	90	1.36	.17	↓	6.0	6.0	1320			
			80	1.32	.15	↓	6.0	6.0	1150			
			70	1.50	.15	↓	6.0	6.1	938			
			65	1.37	.17	↓	6.2	6.2	906			
			60	1.37	.17	↓	6.2	6.2	838			
			55	1.32	.17	↓	6.2	6.3	790			
			50	2.00	.15	.0011	6.4	6.4	750			
			45	2.06	.12	.0012	6.4	6.5	697			
			39	2.30	.06	.0012	6.7	6.9	679			
			Down-stream	8.0 ↓	7.0 ↓	97	1.55	0.22	0.0013 ↓	5.3	6.2	1155
90	1.52	.21				↓	5.3	6.2				1076
80	1.52	.19				↓	5.3	6.3				957
70	1.70	.17				↓	5.4	6.3				832
60	1.70	.15				↓	5.5	6.4				756
55	1.75	.14				↓	5.5	6.5				715
50	1.53	.10				↓	5.5	6.6				694
45	2.05	.01				.0014	5.5	---				650
40	2.25	-.16				.0014	5.5	7.2				650
97	2.09	-.12				.0011	5.5	6.2				1523
6.5 ↓	5.5 ↓	90		2.08	-.11	↓	5.5	6.3	1407			
		80		2.15	-.08	↓	5.5	6.4	1282			
		70		2.19	-.05	↓	5.5	6.5	1151			
		65		2.17	-.04	↓	5.5	6.7	1053			
		60		2.19	-.02	↓	5.5	6.7	991			
		55		2.13	-.02	↓	5.5	6.8	908			
		50		2.31	.02	↓	5.5	7.0	875			
		45		2.39	.05	↓	5.5	7.0	870			

TABLE I. - Concluded. ION-CHAMBER DATA  
(d) High beam current and accelerator comparison. Chamber length, 10 centimeters; nonuniform magnetic field; propellant utilization efficiency,  $\eta_u$ , 80 percent

Accel- erator type	Beam current (cathode ground), $J_g$ , amp	Ion- chamber potential, $V_i$ , v	Accelerator potential, $V_A$ , v	Magnetic field potential difference, $\Delta V_M$ , v	Magnetic field current, $J_M$ , amp	Ion- chamber potential difference, $\Delta V_i$ , v	Current collected by anode, $J_i$ , amp	Current collected by screen and distributor, $J_{SD}$ , amp	Current collected by accelerator, $J_A$ , amp	Filament heating potential difference, $\Delta V_f$ , v	Filament heating current, $J_f$ , amp	Energy dissipated in dis- charge per beam ion, ev/ion
Anode length, 1 cm												
Plate	0.250	4800	-1250	7.0	6.0	80	2.70	0.97	0.0032	10.1	6.5	785
	↑	↑	↑	↑	↑	75	2.75	.92	.0032	10.2	6.7	750
	↑	↑	↑	↑	↑	70	2.82	.87	.0032	10.4	6.8	720
	↑	↑	↑	↑	↑	65	2.90	.81	.0031	10.6	7.0	689
	↑	↑	↑	↑	↑	60	2.90	.72	.0031	10.8	7.1	656
	↑	↑	↑	↑	↑	55	3.00	.67	.0031	11.0	7.2	628
	↑	↑	↑	↑	↑	50	3.10	.60	.0030	11.3	7.4	590
	↑	↑	↑	↑	↑	45	3.20	.55	.0030	11.5	7.6	550
	↑	↑	↑	↑	↑	40	3.30	.50	.0030	11.8	7.8	510
	↑	↑	↑	↑	↑	35	3.40	.45	.0030	12.0	8.0	470
	↑	↑	↑	↑	↑	30	3.50	.40	.0030	12.3	8.3	430
	↑	↑	↑	↑	↑	25	3.60	.35	.0029	12.6	8.6	390
	↑	↑	↑	↑	↑	20	3.70	.30	.0029	12.9	8.9	350
	↑	↑	↑	↑	↑	15	3.85	.25	.0028	13.2	9.2	310
	↑	↑	↑	↑	↑	10	4.00	.20	.0028	13.5	9.5	270
	↑	↑	↑	↑	↑	5	4.20	.15	.0027	13.8	9.8	230
	↑	↑	↑	↑	↑	0	4.40	.10	.0027	14.1	10.1	190
	↑	↑	↑	↑	↑	-5	4.60	.05	.0026	14.4	10.4	150
	↑	↑	↑	↑	↑	-10	4.80	.02	.0026	14.7	10.7	110
	↑	↑	↑	↑	↑	-15	5.00	.01	.0025	15.0	11.0	70
	↑	↑	↑	↑	↑	-20	5.20	.00	.0025	15.3	11.3	30
	↑	↑	↑	↑	↑	-25	5.40	.00	.0024	15.6	11.6	0
	↑	↑	↑	↑	↑	-30	5.60	.00	.0024	15.9	11.9	0
	↑	↑	↑	↑	↑	-35	5.80	.00	.0024	16.2	12.2	0
	↑	↑	↑	↑	↑	-40	6.00	.00	.0024	16.5	12.5	0
	↑	↑	↑	↑	↑	-45	6.20	.00	.0024	16.8	12.8	0
	↑	↑	↑	↑	↑	-50	6.40	.00	.0024	17.1	13.1	0
	↑	↑	↑	↑	↑	-55	6.60	.00	.0024	17.4	13.4	0
	↑	↑	↑	↑	↑	-60	6.80	.00	.0024	17.7	13.7	0
	↑	↑	↑	↑	↑	-65	7.00	.00	.0024	18.0	14.0	0
	↑	↑	↑	↑	↑	-70	7.20	.00	.0024	18.3	14.3	0
	↑	↑	↑	↑	↑	-75	7.40	.00	.0024	18.6	14.6	0
	↑	↑	↑	↑	↑	-80	7.60	.00	.0024	18.9	14.9	0
	↑	↑	↑	↑	↑	-85	7.80	.00	.0024	19.2	15.2	0
	↑	↑	↑	↑	↑	-90	8.00	.00	.0024	19.5	15.5	0
	↑	↑	↑	↑	↑	-95	8.20	.00	.0024	19.8	15.8	0
	↑	↑	↑	↑	↑	-100	8.40	.00	.0024	20.1	16.1	0
	↑	↑	↑	↑	↑	-105	8.60	.00	.0024	20.4	16.4	0
	↑	↑	↑	↑	↑	-110	8.80	.00	.0024	20.7	16.7	0
	↑	↑	↑	↑	↑	-115	9.00	.00	.0024	21.0	17.0	0
	↑	↑	↑	↑	↑	-120	9.20	.00	.0024	21.3	17.3	0
	↑	↑	↑	↑	↑	-125	9.40	.00	.0024	21.6	17.6	0
	↑	↑	↑	↑	↑	-130	9.60	.00	.0024	21.9	17.9	0
	↑	↑	↑	↑	↑	-135	9.80	.00	.0024	22.2	18.2	0
	↑	↑	↑	↑	↑	-140	10.00	.00	.0024	22.5	18.5	0
	↑	↑	↑	↑	↑	-145	10.20	.00	.0024	22.8	18.8	0
	↑	↑	↑	↑	↑	-150	10.40	.00	.0024	23.1	19.1	0
	↑	↑	↑	↑	↑	-155	10.60	.00	.0024	23.4	19.4	0
	↑	↑	↑	↑	↑	-160	10.80	.00	.0024	23.7	19.7	0
	↑	↑	↑	↑	↑	-165	11.00	.00	.0024	24.0	20.0	0
	↑	↑	↑	↑	↑	-170	11.20	.00	.0024	24.3	20.3	0
	↑	↑	↑	↑	↑	-175	11.40	.00	.0024	24.6	20.6	0
	↑	↑	↑	↑	↑	-180	11.60	.00	.0024	24.9	20.9	0
	↑	↑	↑	↑	↑	-185	11.80	.00	.0024	25.2	21.2	0
	↑	↑	↑	↑	↑	-190	12.00	.00	.0024	25.5	21.5	0
	↑	↑	↑	↑	↑	-195	12.20	.00	.0024	25.8	21.8	0
	↑	↑	↑	↑	↑	-200	12.40	.00	.0024	26.1	22.1	0
	↑	↑	↑	↑	↑	-205	12.60	.00	.0024	26.4	22.4	0
	↑	↑	↑	↑	↑	-210	12.80	.00	.0024	26.7	22.7	0
	↑	↑	↑	↑	↑	-215	13.00	.00	.0024	27.0	23.0	0
	↑	↑	↑	↑	↑	-220	13.20	.00	.0024	27.3	23.3	0
	↑	↑	↑	↑	↑	-225	13.40	.00	.0024	27.6	23.6	0
	↑	↑	↑	↑	↑	-230	13.60	.00	.0024	27.9	23.9	0
	↑	↑	↑	↑	↑	-235	13.80	.00	.0024	28.2	24.2	0
	↑	↑	↑	↑	↑	-240	14.00	.00	.0024	28.5	24.5	0
	↑	↑	↑	↑	↑	-245	14.20	.00	.0024	28.8	24.8	0
	↑	↑	↑	↑	↑	-250	14.40	.00	.0024	29.1	25.1	0
	↑	↑	↑	↑	↑	-255	14.60	.00	.0024	29.4	25.4	0
	↑	↑	↑	↑	↑	-260	14.80	.00	.0024	29.7	25.7	0
	↑	↑	↑	↑	↑	-265	15.00	.00	.0024	30.0	26.0	0
	↑	↑	↑	↑	↑	-270	15.20	.00	.0024	30.3	26.3	0
	↑	↑	↑	↑	↑	-275	15.40	.00	.0024	30.6	26.6	0
	↑	↑	↑	↑	↑	-280	15.60	.00	.0024	30.9	26.9	0
	↑	↑	↑	↑	↑	-285	15.80	.00	.0024	31.2	27.2	0
	↑	↑	↑	↑	↑	-290	16.00	.00	.0024	31.5	27.5	0
	↑	↑	↑	↑	↑	-295	16.20	.00	.0024	31.8	27.8	0
	↑	↑	↑	↑	↑	-300	16.40	.00	.0024	32.1	28.1	0
	↑	↑	↑	↑	↑	-305	16.60	.00	.0024	32.4	28.4	0
	↑	↑	↑	↑	↑	-310	16.80	.00	.0024	32.7	28.7	0
	↑	↑	↑	↑	↑	-315	17.00	.00	.0024	33.0	29.0	0
	↑	↑	↑	↑	↑	-320	17.20	.00	.0024	33.3	29.3	0
	↑	↑	↑	↑	↑	-325	17.40	.00	.0024	33.6	29.6	0
	↑	↑	↑	↑	↑	-330	17.60	.00	.0024	33.9	29.9	0
	↑	↑	↑	↑	↑	-335	17.80	.00	.0024	34.2	30.2	0
	↑	↑	↑	↑	↑	-340	18.00	.00	.0024	34.5	30.5	0
	↑	↑	↑	↑	↑	-345	18.20	.00	.0024	34.8	30.8	0
	↑	↑	↑	↑	↑	-350	18.40	.00	.0024	35.1	31.1	0
	↑	↑	↑	↑	↑	-355	18.60	.00	.0024	35.4	31.4	0
	↑	↑	↑	↑	↑	-360	18.80	.00	.0024	35.7	31.7	0
	↑	↑	↑	↑	↑	-365	19.00	.00	.0024	36.0	32.0	0
	↑	↑	↑	↑	↑	-370	19.20	.00	.0024	36.3	32.3	0
	↑	↑	↑	↑	↑	-375	19.40	.00	.0024	36.6	32.6	0
	↑	↑	↑	↑	↑	-380	19.60	.00	.0024	36.9	32.9	0
	↑	↑	↑	↑	↑	-385	19.80	.00	.0024	37.2	33.2	0
	↑	↑	↑	↑	↑	-390	20.00	.00	.0024	37.5	33.5	0
	↑	↑	↑	↑	↑	-395	20.20	.00	.0024	37.8	33.8	0
	↑	↑	↑	↑	↑	-400	20.40	.00	.0024	38.1	34.1	0
	↑	↑	↑	↑	↑	-405	20.60	.00	.0024	38.4	34.4	0
	↑	↑	↑	↑	↑	-410	20.80	.00	.0024	38.7	34.7	0
	↑	↑	↑	↑	↑	-415	21.00	.00	.0024	39.0	35.0	0
	↑	↑	↑	↑	↑	-420	21.20	.00	.0024	39.3	35.3	0
	↑	↑	↑	↑	↑	-425	21.40	.00	.0024	39.6	35.6	0
	↑	↑	↑	↑	↑	-430	21.60	.00	.0024	39.9	35.9	0
	↑	↑	↑	↑	↑	-435	21.80	.00	.0024	40.2	36.2	0
	↑	↑	↑	↑	↑	-440	22.00	.00	.0024	40.5	36.5	0
	↑	↑	↑	↑	↑	-445	22.20	.00	.0024	40.8	36.8	0
	↑	↑	↑	↑	↑	-450	22.40	.00	.0024	41.1	37.1	0
	↑	↑	↑	↑	↑	-455	22.60	.00	.0024	41.4	37.4	0
	↑	↑	↑	↑	↑	-460	22.80	.00	.0024	41.7	37.7	0
	↑	↑	↑	↑	↑	-465	23.00	.00	.0024	42.0	38.0	0
	↑	↑	↑	↑	↑	-470	23.20	.00	.0024	42.3	38.3	0
	↑	↑	↑	↑	↑	-475	23.40	.00	.0024	42.6	38.6	0
	↑	↑	↑	↑	↑	-480	23.60	.00	.0024	42.9		

TABLE II. - OVERALL ENGINE PERFORMANCE  
[Nonuniform magnetic field.]

Ion-chamber potential, $V_i$ , v	Accelerator potential, $V_a$ , v	Beam current (common ground), $J_b$ , amp	Magnetic-field potential difference, $\Delta V_M$ , v	Magnetic-field current, $J_M$ , amp	Ion-chamber potential difference, $\Delta V_i$ , v	Current collected by anode, $J_i$ , amp	Current collected by accelerator, $J_A$ , amp	Filament heating potential difference, $\Delta V_f$ , v	Filament heating current, $J_f$ , amp	Energy dissipated in discharge per ion, eV/ion	Specific impulse, sec	Overall tower efficiency, $\eta$ , %	Thrust, mlt
4000	1100	0.250	7.0	6.5	55	3.55	0.0025	6.5	10.0	612	6300	0.772	7.2
7000	1400	.250	↑	6.1	50	3.10	.0020	7.3	10.2	570	8400	.863	9.4
4500	1250	.250	6.0	6.0	45	3.20	.0030	7.6	11.3	531	6900	.811	7.9
2500	1000	.125	6.0	↑	50	1.51	.0002	6.7	10.8	554	5000	.637	2.9
2500	1000	.125	6.0	↑	55	1.43	.0002	6.6	10.7	574	5000	.636	2.9
5500	1250	.340	7.0	↑	62	4.70	.0040	7.6	11.0	722	7400	.524	11.4
5800	1250	.405	↑	↑	74	4.80	.0040	7.6	11.0	803	7800	.531	14.0
6100	1200	.400	↑	↑	68	5.00	.0042	8.4	11.0	782	8000	.544	14.8
4600	1400	.250	9.0	6.6	55	5.00	.0050	10.0	20.0	751	6300	.721	10.0
3500	500	.510	7.0	5.6	47	8.40	.0065	9.0	22.0	727	5900	.738	13.9
6250	1750	.250	↑	6.3	50	2.30	.0022	7.7	10.4	410	7900	.867	9.0
6000	1500	.250	↑	↑	↑	2.15	.0022	6.9	10.5	340	7750	.869	8.1
5500	1500	.250	↑	↑	↑	2.40	.0025	7.1	10.7	430	7400	.643	6.4
5600	1600	.260	↑	↑	↑	2.55	.0050	7.2	10.9	460	7070	.522	8.2



E-1453

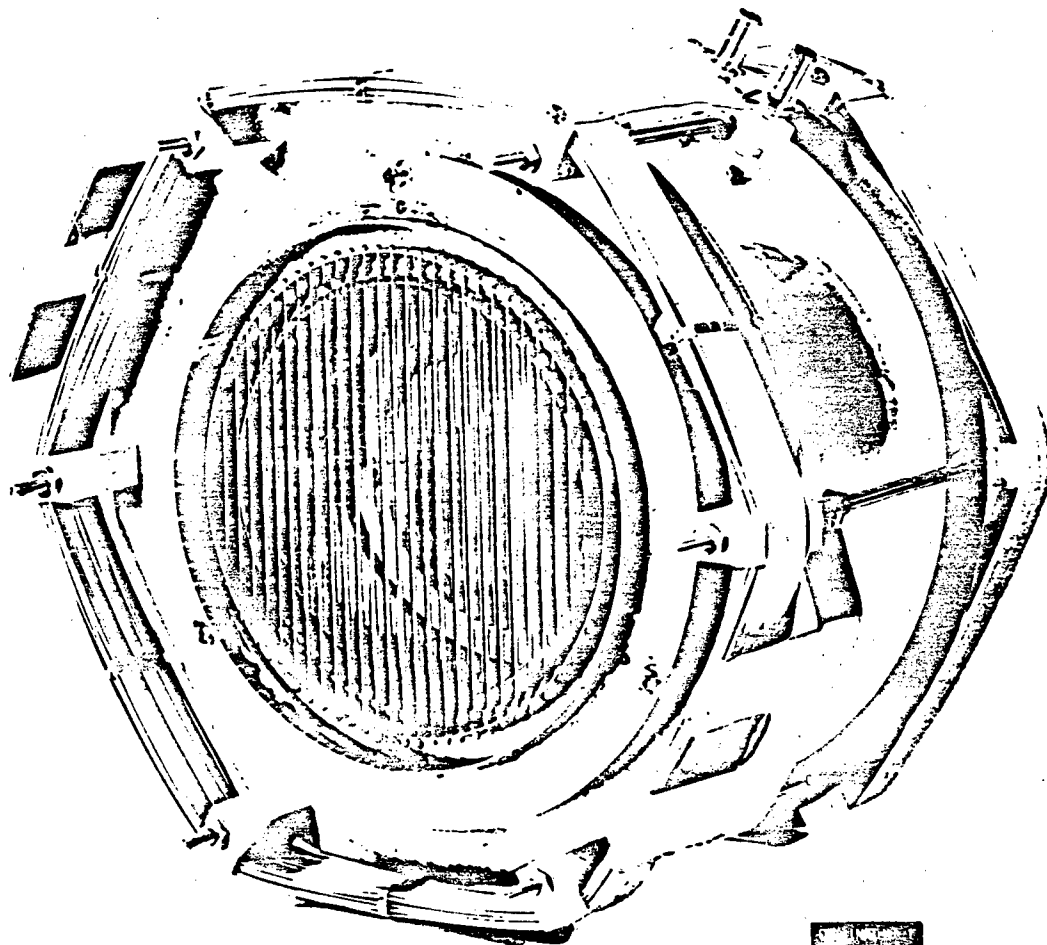
TABLE III. - THRUST TARGET DATA

## (a) Thrust measurements

Accelerator system	Specific impulse, sec	Beam current (common ground), $J_B$ , amp	Target current, $J_t$ , amp	$J_t/J_B$	Theoretical thrust, $F_c$ , mlb	Estimated target force, $J_t/J_B \times F_c$ , mlb	Measured thrust, $F_m$ , mlb	Measured thrust/Estimated target force
Plate ↓	5000	0.125	0.037	0.296	2.67	0.85	0.55	0.65
	5000	.125	.037	.296	2.67	.85	.62	.73
	6300	.127	.070	.550	3.63	2.00	1.93	.96
	5500	.127	.050	.395	3.06	1.21	1.10	.91
Wire	6300	.125	-----	.40	3.63	1.45	1.43	.99
				.45	3.63	1.83	1.43	.88
Wire	6300	.200	-----	.40	5.82	2.33	1.87	.80
				.45	5.82	2.52	1.87	.71

(b) Thrust target voltage and current. Beam current (common ground),  $J_B$ , 0.125 ampere; accelerator potential,  $V_A$ , -1250 volts; chamber length, 10 centimeters; anode length, 7.5 centimeters; plate accelerators; nonuniform magnetic field

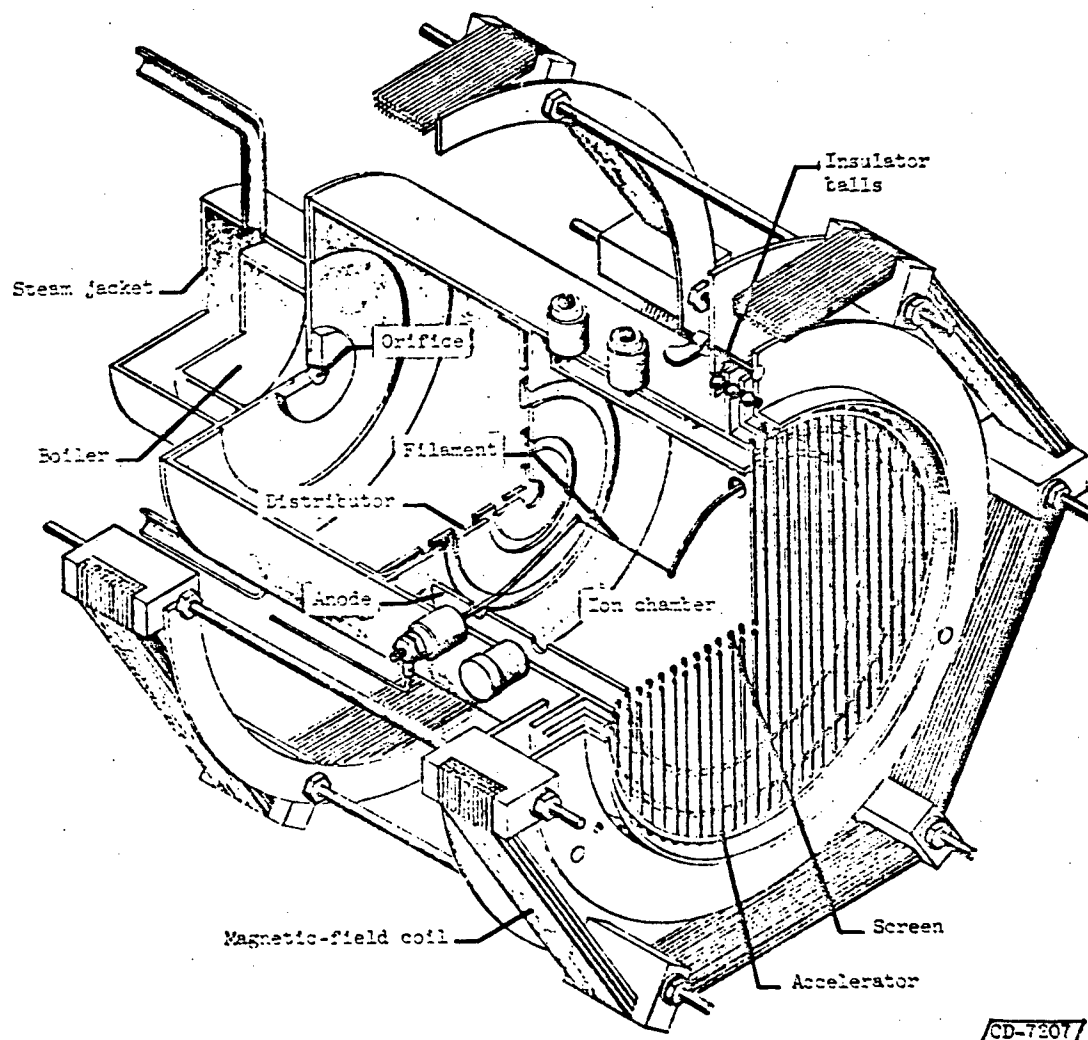
Heated filament neutralizer	Target potential, $V_T$ , v	Current collected by target, $J_T$ , amp	Ion-chamber potential, $V_I$ , v	Magnetic field potential difference, $\Delta V_M$ , v	Magnetic field current, $J_M$ , amp	Ion-chamber potential difference, $\Delta V_I$ , v	Current collected by anode, $J_I$ , amp	Current collected by screen and distributor, $J_{SD}$ , amp	Current collected by accelerator, $J_A$ , amp
Off	770	0.035	2000	7.0	6.3	60	1.53	0.11	0.0013
	1010	.038	2500	↓	6.0	65	1.45	.11	.0012
	1280	.042	3000		6.4	48	1.36	.09	.0011
	1550	.051	3500		6.4	46	1.35	.08	.0010
	1750	.071	4000		6.35	44	1.32	.07	.0011
On	10	0.035	2000	7.0	6.3	60	1.53	0.11	0.0013
	11	.038	2500	↓	6.0	65	1.45	.11	.0013
	11	.050	3000		6.4	48	1.36	.09	.0011
	12	.055	3500		6.4	46	1.35	.08	.0010
	12	.073	4000		6.35	44	1.32	.07	.0011



C-54010

Figure 1. - Electron-bombardment ion engine.

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CD-7201

Figure 2. - Cutaway sketch of engine.

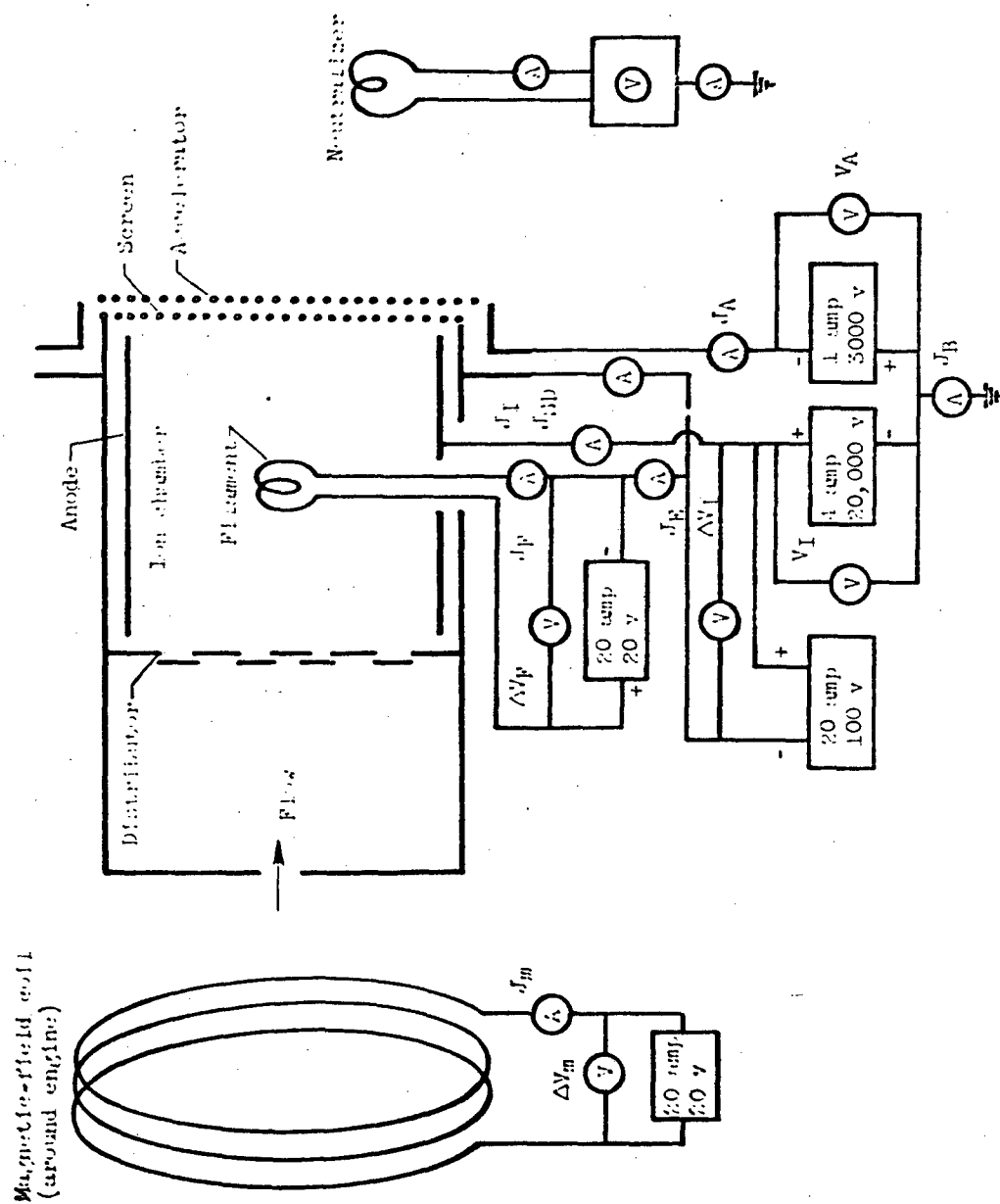


Figure 3. - Wiring diagram of ion engine.

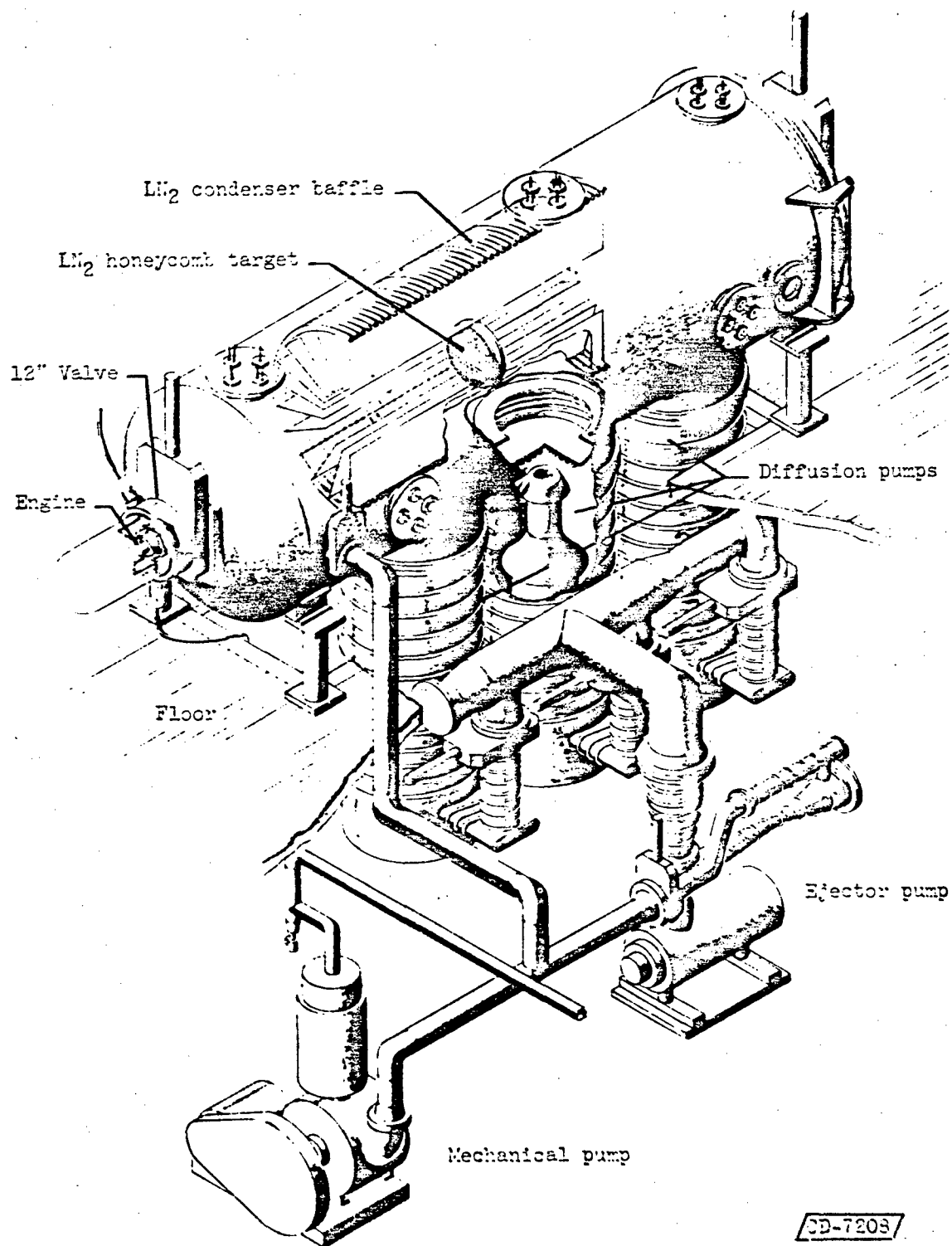


Figure 4. - Sketch of complete engine and vacuum-tank installation.

CD-7203

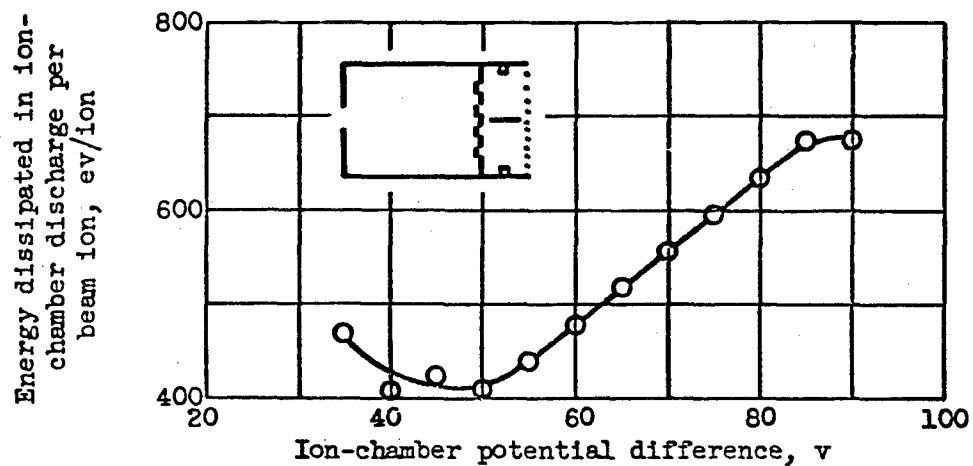


Figure 5. - General ion-chamber performance characteristics. 0.125-Ampere beam current at a specific impulse of 7000 seconds; nonuniform magnetic field with strength of 32 gauss at center of filament; propellant utilization efficiency, 0.75.

E-1433

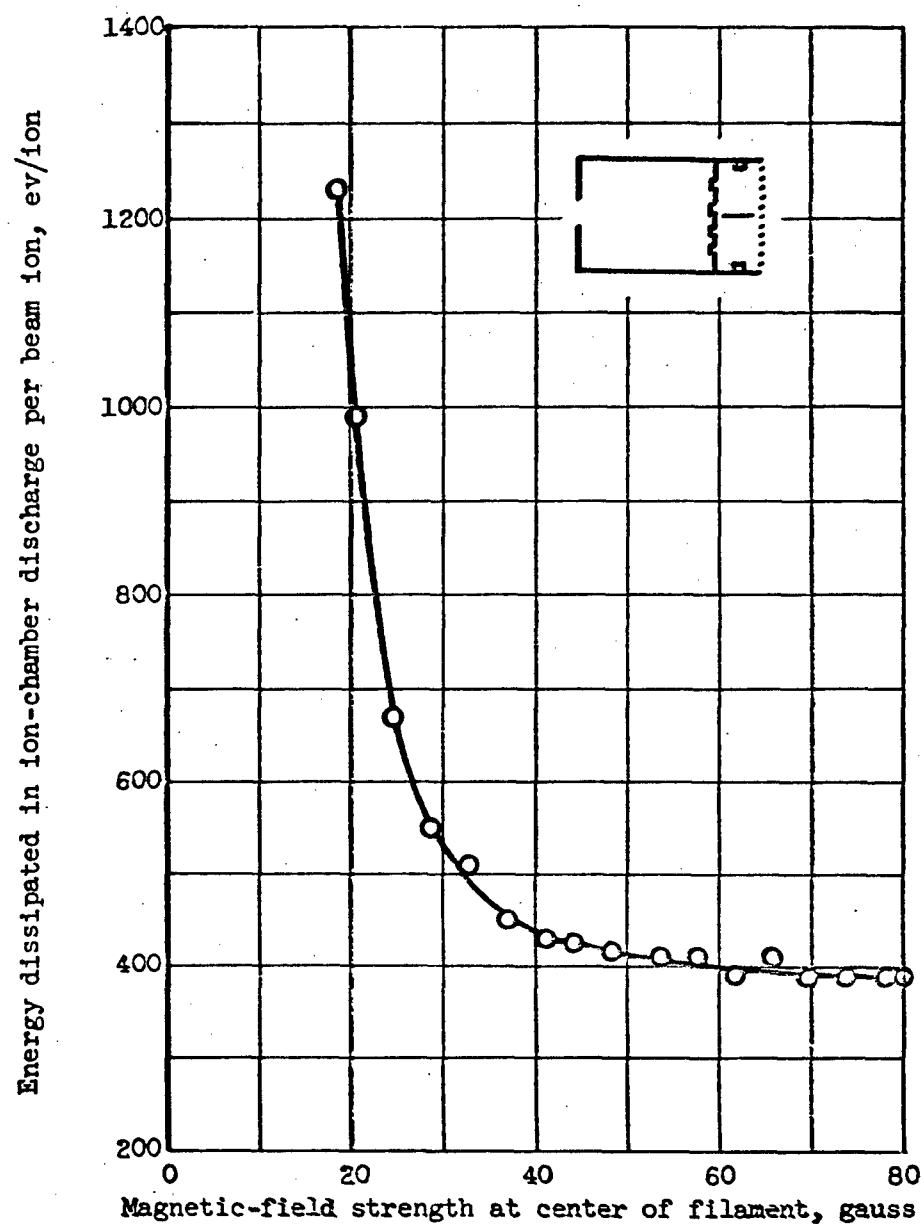


Figure 6. - Effect of magnetic-field strength on ion-chamber performance. 0.125-Ampere beam current at a specific impulse of 7000 seconds; ion-chamber potential difference, 50 volts; propellant utilization efficiency, 0.8.

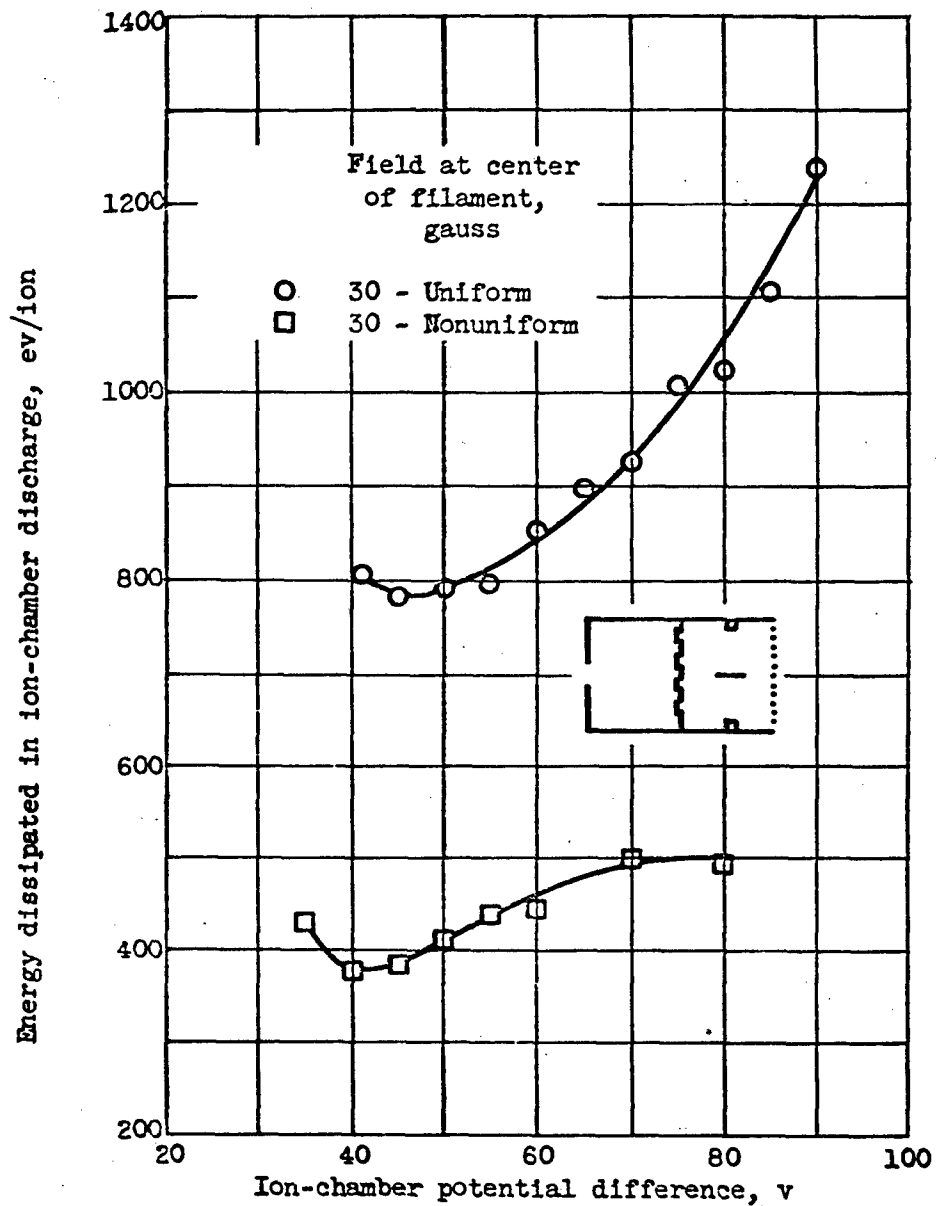
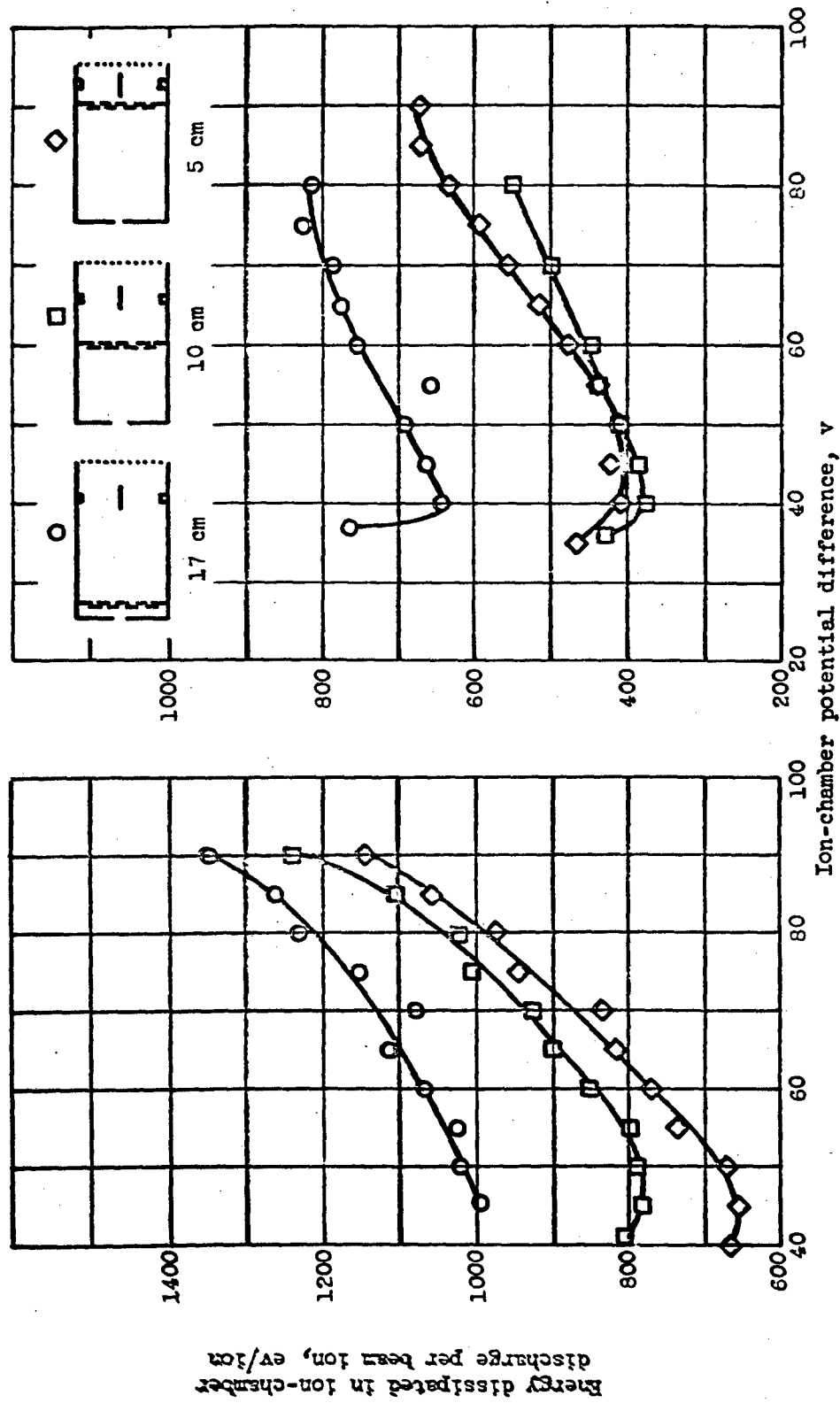


Figure 7. - Effect of magnetic-field shape on ion-chamber performance at a beam current of 0.125 ampere. Specific impulse, 7000 seconds; 1-centimeter anode was used with a 10-centimeter chamber length.





(a) Uniform magnetic field, 30 gauss at filament.  
 (b) Nonuniform field, 30 gauss at filament.  
 Figure 8. - Effect of chamber length on ion-chamber performance. 0.125-Ampere beam current at specific impulse of 7000 seconds.

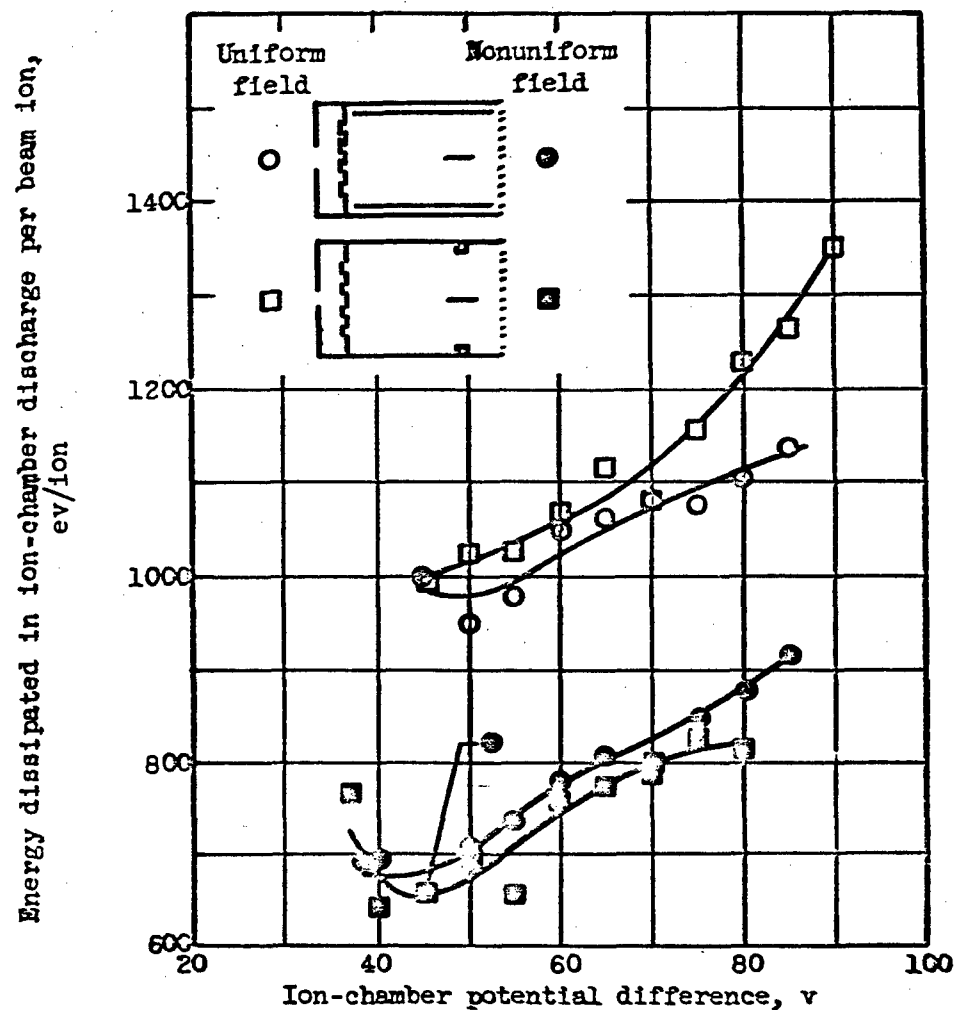


Figure 9. - Effect of anode length on ion-chamber performance with 30-gauss field strength at the filament. 0.125-Ampere beam current at 7000-second impulse; ion-chamber length, 17 centimeters.

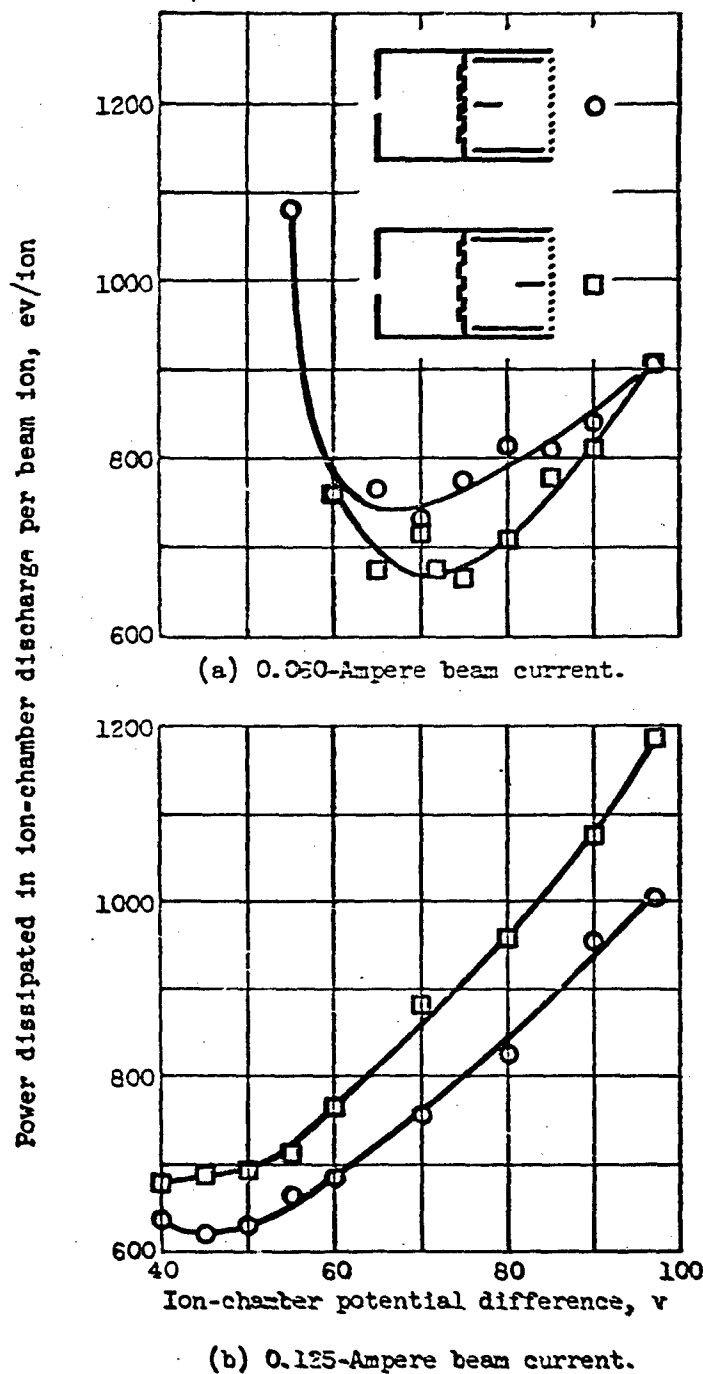


Figure 10. - Effect of filament position on ion-chamber efficiency. Nonuniform magnetic field with strength of 35 gauss at center of chamber; specific impulse, 4500 seconds; a 7.5-centimeter-long anode was used in a 10-centimeter-long ion chamber.

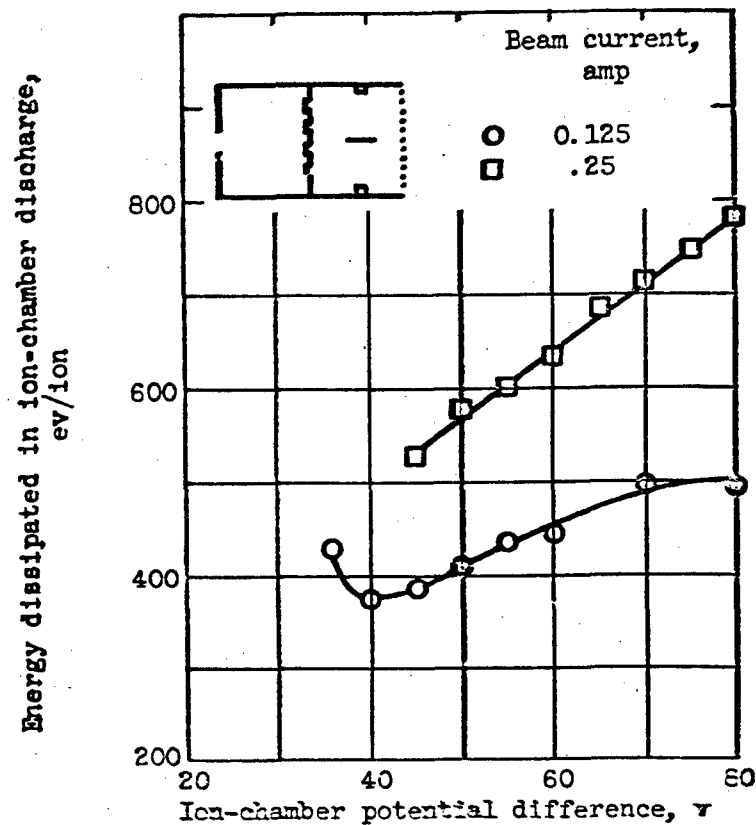
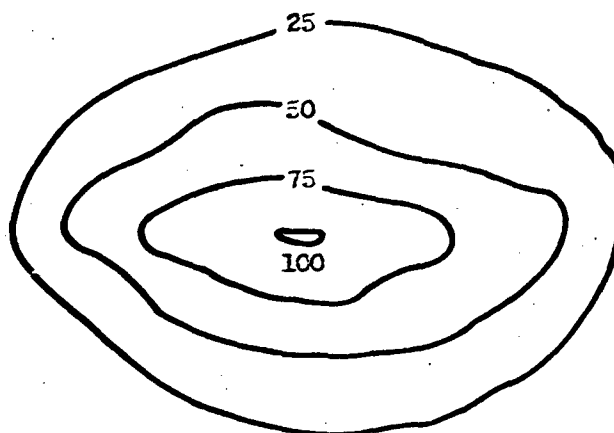
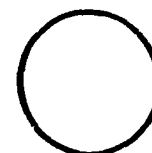


Figure 11. - Effect of beam current on ion-chamber performance at a specific impulse of 7000 seconds. Nonuniform magnetic-field strength, 30 gauss at center of chamber; propellant utilization efficiency, 80 percent; 1-centimeter-long anode used in 10-centimeter-long ion chamber.

Percent of maximum

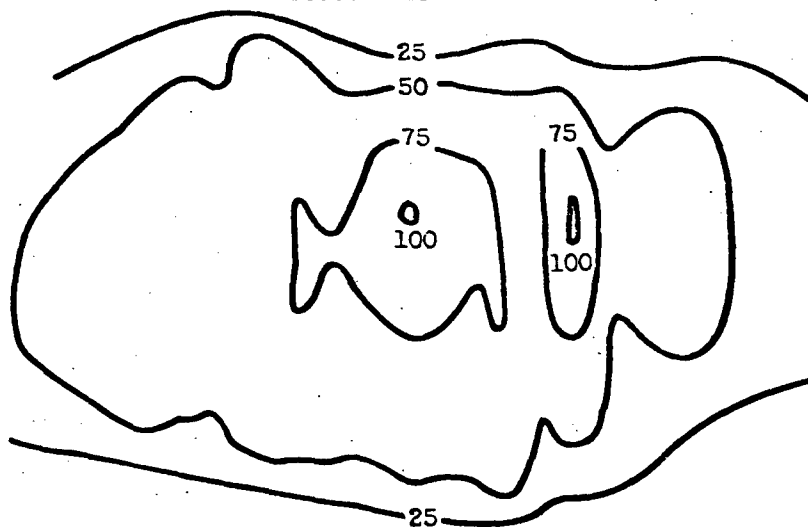


(a) Plate grid, 0.125-ampere beam at specific impulse of 5000 seconds.



10-Cm-diam.  
source

Percent of maximum



(b) Wire grid; 0.125-ampere beam at specific impulse of 6300 seconds.

Figure 12. - Comparison of beam power distribution for plate and wire accelerator systems. 1 Meter downstream of engine.

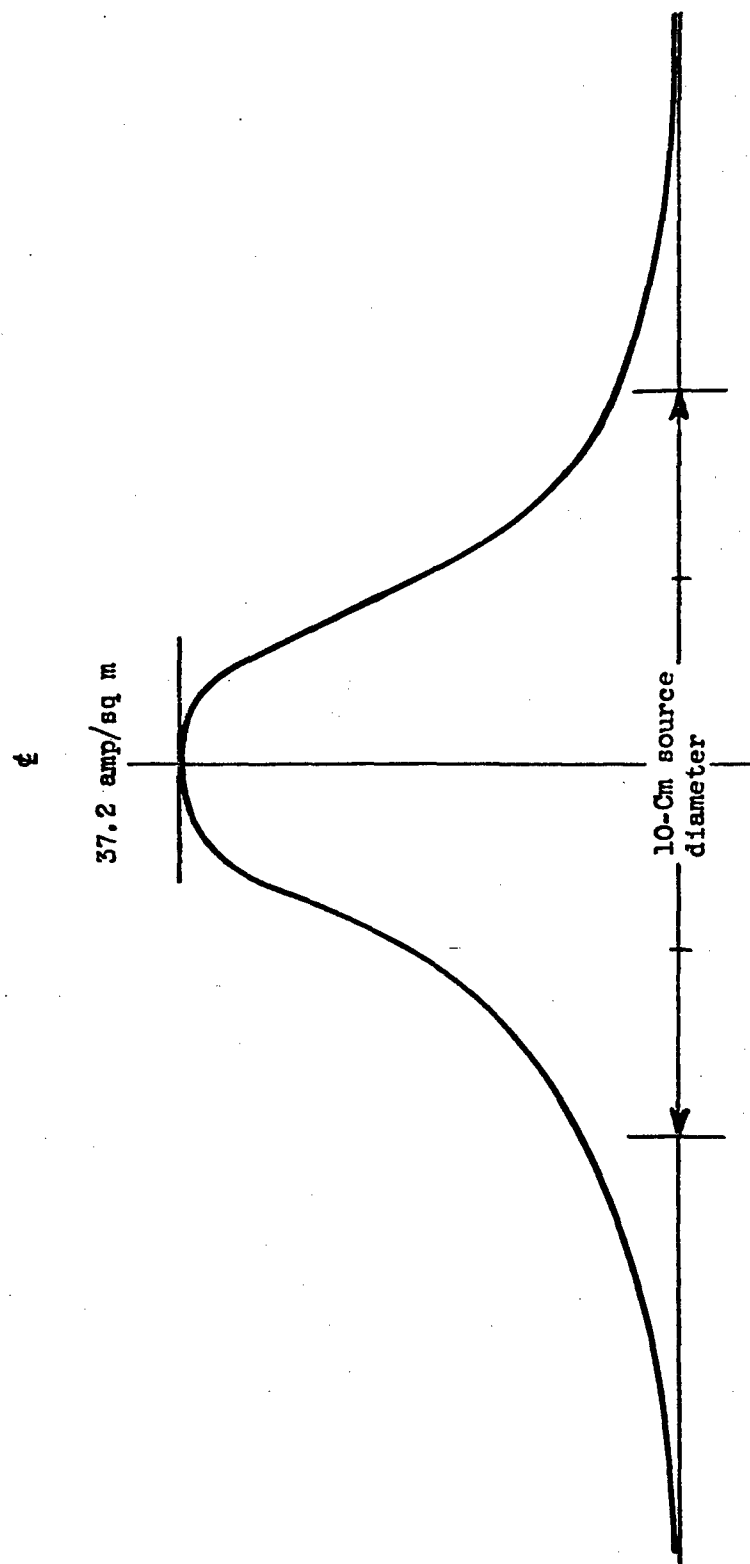


Figure 13. - Current distribution across downstream face of accelerator. 1/8-Ampere beam current at specific impulse of 6000 seconds.

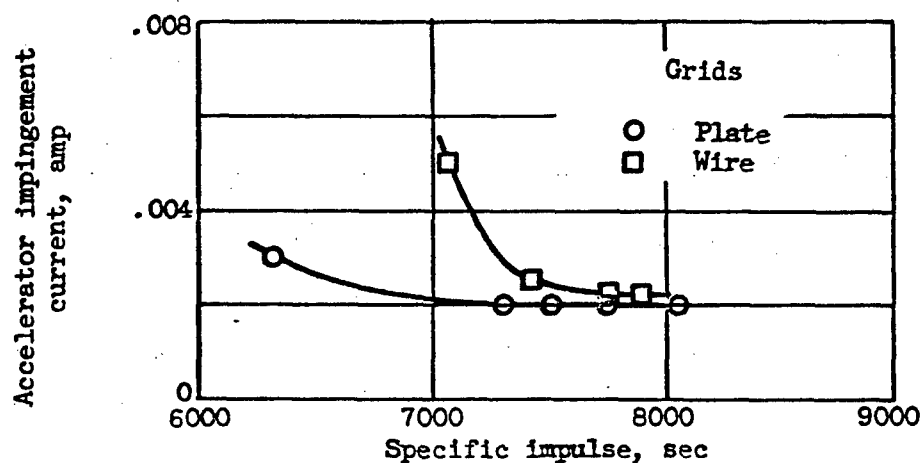


Figure 14. - Effect of specific impulse on accelerator impingement current at 0.25-ampere beam current. Propellant utilization efficiency, 80 percent.

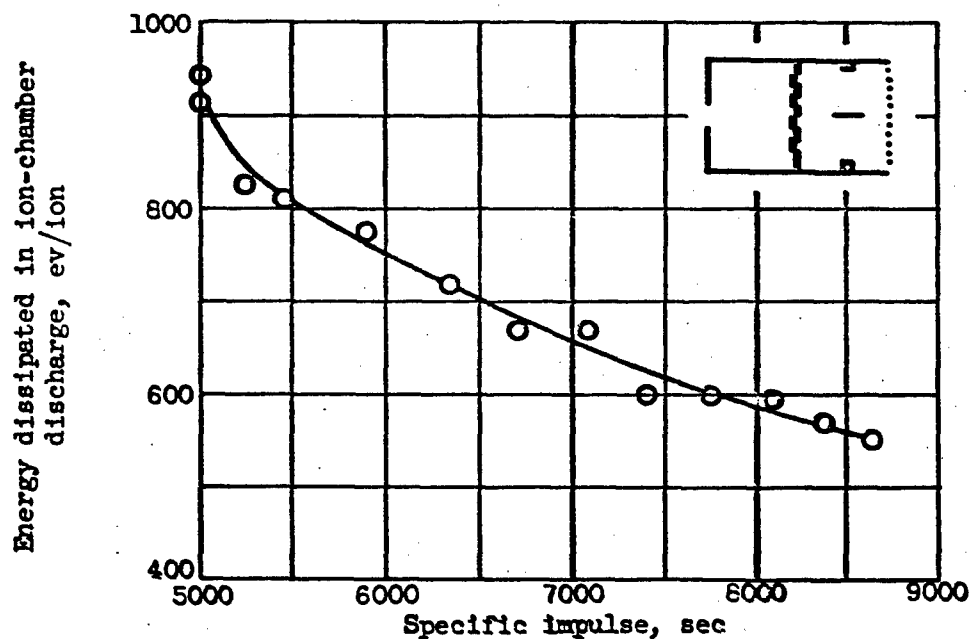
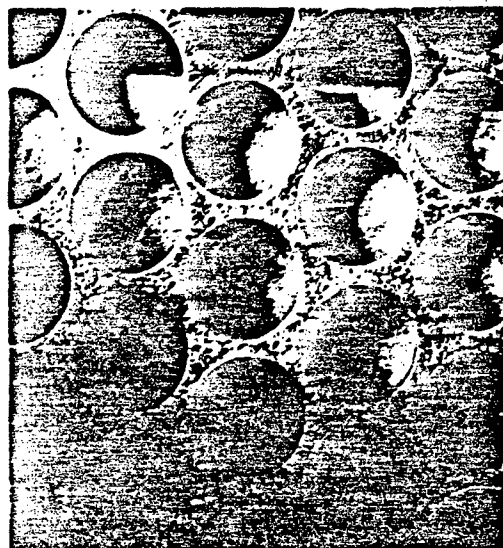


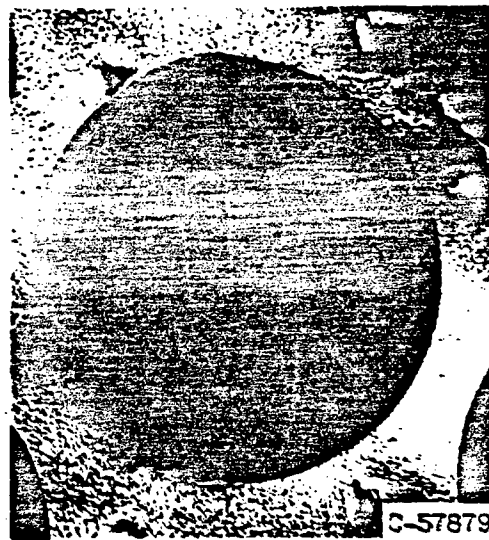
Figure 15. - Effect of specific impulse on ion-chamber efficiency with 0.125-ampere beam at propellant utilization efficiency of 80 percent. Nonuniform magnetic field; 1-centimeter anode in 10-centimeter-long ion chamber.



(a) General view of upstream face of accelerator grid after run.



Before



After

(b) Closeup of center hole.

Figure 16. - Impingement damage to molybdenum accelerator during 150-hour run with 0.2-ampere beam at specific impulse of 5000 seconds.



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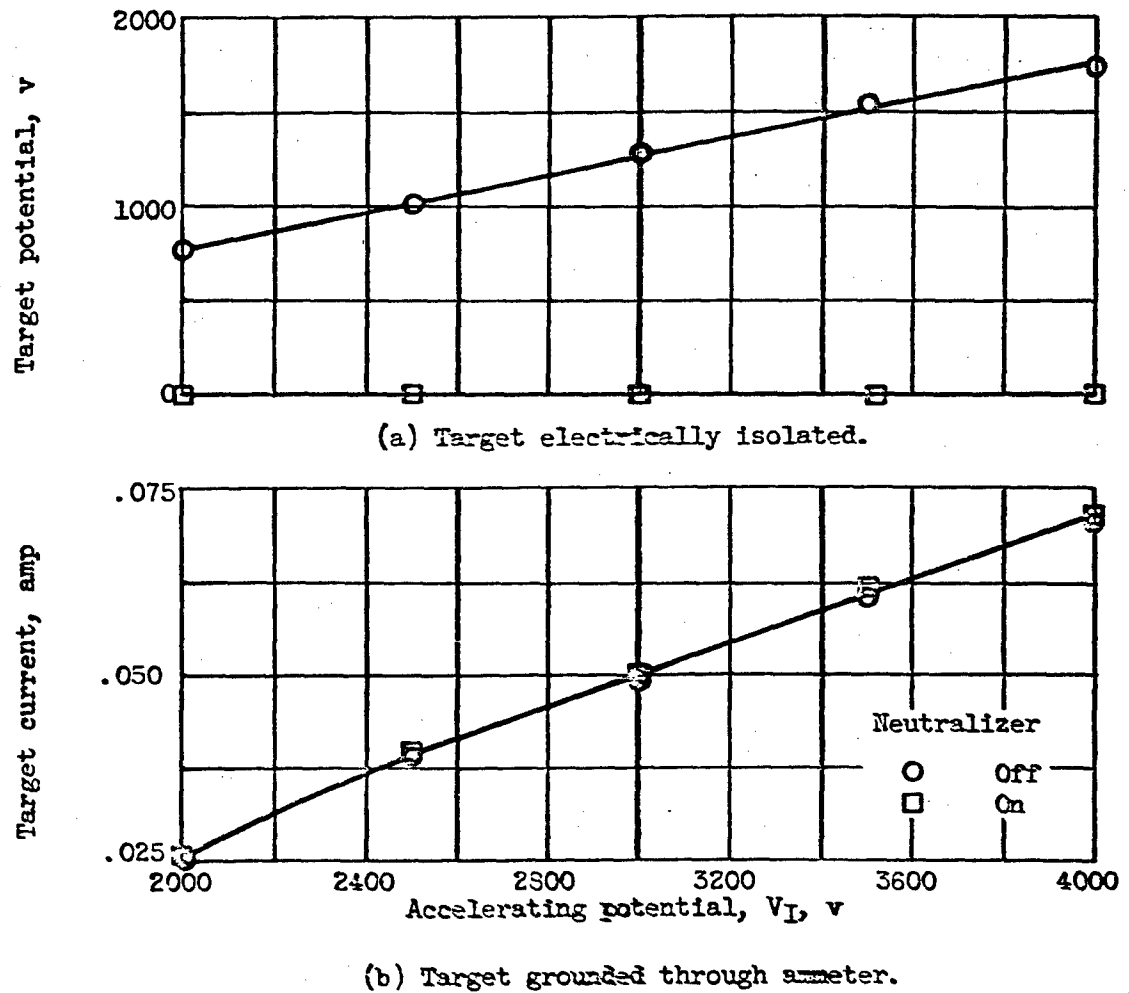


Figure 17. - Thrust target current and voltage as a function of net accelerating potential with and without neutralizer.

<p>NASA TN D-1163 National Aeronautics and Space Administration, INVESTIGATION OF A 10-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT ION ROCKET. Paul D. Reader. January 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1163)</p> <p>This report deals with an improved 10-cm-diam. electron-bombardment ion rocket capable of opera- tion in performance regimes above 10 milb of thrust. The source has been operated above 10 milb of thrust continuously for 10 hr at a specific impulse of 6500 sec. The source has produced 0.5-amp beam currents at as low an impulse as 5900 sec, yielding a theoretical thrust of 13 milb. Accelerator impinge- ment currents have been on the order of 1 percent of the beam current. Mercury was used as a propellant during this investigation.</p> <p>Copies obtainable from NASA, Washington</p>	<p>I. Reader, Paul D. II. NASA TN D-1163 (Initial NASA distribution: 20, Fluid mechanics; 41, Propulsion systems, electric.)</p>	<p>NASA TN D-1163 National Aeronautics and Space Administration, INVESTIGATION OF A 10-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT ION ROCKET. Paul D. Reader. January 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1163)</p> <p>This report deals with an improved 10-cm-diam. electron-bombardment ion rocket capable of opera- tion in performance regimes above 10 milb of thrust. The source has been operated above 10 milb of thrust continuously for 10 hr at a specific impulse of 6500 sec. The source has produced 0.5-amp beam currents at as low an impulse as 5900 sec, yielding a theoretical thrust of 13 milb. Accelerator impinge- ment currents have been on the order of 1 percent of the beam current. Mercury was used as a propellant during this investigation.</p> <p>Copies obtainable from NASA, Washington</p>	<p>I. Reader, Paul D. II. NASA TN D-1163 (Initial NASA distribution: 20, Fluid mechanics; 41, Propulsion systems, electric.)</p>	<p>NASA TN D-1163 National Aeronautics and Space Administration, INVESTIGATION OF A 10-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT ION ROCKET. Paul D. Reader. January 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1163)</p> <p>This report deals with an improved 10-cm-diam. electron-bombardment ion rocket capable of opera- tion in performance regimes above 10 milb of thrust. The source has been operated above 10 milb of thrust continuously for 10 hr at a specific impulse of 6500 sec. The source has produced 0.5-amp beam currents at as low an impulse as 5900 sec, yielding a theoretical thrust of 13 milb. Accelerator impinge- ment currents have been on the order of 1 percent of the beam current. Mercury was used as a propellant during this investigation.</p> <p>Copies obtainable from NASA, Washington</p>	<p>I. Reader, Paul D. II. NASA TN D-1163 (Initial NASA distribution: 20, Fluid mechanics; 41, Propulsion systems, electric.)</p>
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